The Impact of Carbon Taxes on Market Structure: Evidence from British Columbia's Retail Gasoline Industry

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Abstract

As shown by Buchanan (1969), the efficient tax on a monopoly is lower than on a competitive industry (due to market power of the monopolist). I build on this idea and show that, in oligopoly markets, the market power problem is exacerbated in the long run. I then illustrate this effect by studying short-run and long-run changes in British Columbia's retail gasoline industry following the implementation of a carbon tax. First, I use a theoretical model to illustrate the *direct effect* (in the short run) and the *market-structure effect* (in the long run). The direct effect is an increase in marginal cost that is partially passed-through to consumers. The market-structure effect is a reduction in the number of firms due to lower margins following the tax, which in turn further increases price. Second, I use panel data on retail prices, retail margins, and the number of gasoline stations to empirically estimate the short-run and long-run impacts of a carbon tax. My empirical results are consistent with theory, and suggest that incomplete passthrough of the tax caused some stations to exit resulting in even greater long-run price increases.

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1 Introduction

Reducing human-caused climate change has become an important objective for policy makers. As of 2019, 46 national and 28 subnational jurisdictions have a carbon pricing system in place (World Bank Group, 2019). Many greenhouse gas reduction strategies use carbon taxes, which are based on the idea that incorporating the *social cost of carbon* (SCC) in prices for goods and services will eliminate negative externalities.[1] If neither producers nor consumers pay the SCC in market transactions, then output is higher than socially optimal. In competitive markets, setting a carbon tax equal to the SCC can account for the negative externality, and rectify the problem. The tax raises marginal cost causing firms to reduce output, or to exit the market if they are unable to achieve positive profit. This increases the price paid by consumers, decreases the price received by producers, and creates a wedge between them that is collected as tax revenue. The resulting equilibrium is socially efficient because the marginal benefit of consumption is equated with the sum of the marginal cost of production and the SCC.

In contrast, the same policy applied to an imperfectly competitive market will not be socially efficient. As noted by Buchanan (1969), imposing a SCC-valued tax on a monopoly will reduce quantity, and increase price, past the socially efficient level. This is because market power causes firms to restrict output below the competitive level. It follows from his analysis that, in imperfectly competitive markets with an externality, the efficient tax is less than the marginal damages of the externality (i.e. less than the SCC).[2] However, the monopoly setting that Buchanan analyses is static in the sense that it does not consider changes in the number of firms. If the monopoly firm exits, then the market would cease to exist. The contribution of this paper is to show that, in an oligopoly setting, a tax could reduce the number of firms in the long run, and exacerbate the market-power problem.

In this paper I study the introduction of a carbon tax in the Canadian province of British Columbia (BC) and distinguish between short-run and long-run effects in the retail gasoline industry. First, I characterize short-run and long-run impacts of a tax in a theoretical model of oligopolistic competition. Second, to test the predictions of the theoretical model, I employ a difference-in-difference (DiD) estimator to identify changes in prices, margins, and the number of firms.

To fix ideas, I distinguish between the *direct effect*, and the *market-structure effect* of a tax in the oligopolistic model. The direct effect of the tax is the impact on price and

[1] The social cost of carbon is a monetary value for the negative externalities associated with carbon emissions. Recent estimates place the SCC at \$42.93 as of 2016, with an expected real increase up to \$57.49 in 2030 (Environment and Climate Change Canada, 2016).

[2] See also Barnett (1980), who extends Buchanan's work by showing that optimal tax rates may be lower than marginal damages if polluters are imperfectly competitive, and that the difference between the optimal tax and the marginal damages is larger when demand is more inelastic.

quantity in the short run, before firms are able to adjust fixed costs. The market-structure effect is the impact on price and quantity due to changes in the number of firms when fixed costs become adjustable. As in Buchanan (1969), the effect of a tax in the short run will be to increase price (reduce output) past the socially efficient level. However, if the tax reduces the number of firms in the long run, then greater market power will exacerbate the problem by further increasing price and reducing output. Overall, the long-run impact of the tax is the combination of the direct and market-structure effects.

To test the model's predictions, I estimate changes in BC's retail gasoline industry following the introduction of the British Columbia Carbon Tax (BCCT). The BCCT is a broad-based tax that was introduced on July 1st 2008 at $10 per tonne of *carbon dioxide equivalent* emissions, and was scheduled to rise at annual intervals of $5 per tonne up to $30 per tonne on July 1st 2012.[3] The BCCT acts as a good natural experiment for two key reasons. First, its surprise implementation meant that consumers and producers were unable to respond in advance of the policy change.[4] Second, many other Canadian provinces did not see changes in gasoline taxes for many years before or after, and can be used as a control group to identify the causal impact of the BCCT on retail gasoline markets. I focus on the retail gasoline industry because local market power of retail gasoline stations has been attributed to higher prices (see Verlinda (2008); Deltas (2008)), and the industry accounts for a sizable portion of emissions.[5]

I use panel data from Statistics Canada and Kent Group Ltd. to quantify the impact of the carbon tax in BC. I observe retail prices and margins at the city level, as well as the number of gasoline stations by census division. I estimate the impact of the BCCT on retail gasoline markets using a difference-in-difference (DiD) approach where other Canadian provinces act as a control group, and I vary the post-treatment period to capture differences between short-run and long-run effects. Since the BCCT rose at scheduled one year intervals in its first four years, I split the post BCCT timeframe into eight one-year periods and estimate separate DiD models for each one. Each DiD regression includes one of the eight post-treatment periods and a common pre-treatment period. This method generates estimates for the impact of the BCCT in each of the eight consecutive years following the introduction of the tax.

My results suggest that incomplete passthrough in the short run caused exit and greater market concentration at the station level, which in turn contributed to a long-run price increase that is larger than the tax increase. I estimate decreases in the retail margin of

[3]Carbon dioxide equivalent emissions measure the amount of a greenhouse gas that has the same global warming potential as carbon dioxide.

[4]The BCCT was first announced on February 19th, 2008, less than five months before it came into effect on July 1st, 2008.

[5]In 2016, passenger cars and passenger light trucks made up 12.09% of Canada's total CO2 equivalent emissions while freight trucks accounted for an additional 8.52% (Environment and Climate Change Canada, 2018a,b).

3.68 ¢/ltr and 3.62 ¢/ltr in the first two years after the last tax increase. This is a significant decrease in retail margins, which averaged 8.32 ¢/ltr in BC during the pre-treatment period. The initial decrease in margins is followed by a reduction in stations and a return of the margins to pre-BCCT levels. I estimate a retail price increase of 3.36 ¢/ltr in the year after the last tax increase, but four years later the estimated price increase is 7.68 ¢/ltr, even though the tax did not change. Additionally, the number of stations in BC decreased by 7.42% in the long run, which I take as confirmation of the hypothesis that the long-run price increase is the result of changes in market structure.

These findings are important for understanding the economic impacts of carbon taxes. In order for policy makers to select the optimal tax level they need to consider both short-run and long-run policy outcomes. My results demonstrate that this issue is relevant in the context of BC's retail gasoline market, but other energy intensive industries could also experience similar effects.

There is a growing literature on the impacts of the BCCT; some initial studies have shown decreases in emissions and/or fuel consumption due to the BCCT (Elgie and McClay, 2013; Beck et al., 2015; Bernard et al., 2014; Rivers and Schaufele, 2015).[6] In a recent paper, Pretis (2019) finds no evidence of a decrease in aggregate CO_2 emissions but finds significant decreases in certain sectors (including transportation). Rivers and Schaufele (2015) estimate gasoline demand elasticities and find that the short-run demand response to the carbon tax is significantly larger than the response to non-tax changes in gasoline price; this finding is consistent with Li et al. (2014), who perform a similar analysis on U.S. data. However, an analysis by Erutku and Hildebrand (2018) suggests that the magnitude of this demand response in BC faded over time. Beck et al. (2015) examine income redistribution due to the BCCT, while Bernard and Kichian (2019) and Metcalf (2016) study the impact on GDP. Yamazaki (2017) studies the effect on employment noting that carbon intensive industries lose jobs, but there is an overall net gain in employment. Antweiler and Gulati (2016) study the impact on vehicle use and new vehicle purchase. One area that, until now, has not been considered in the literature is the link between policy-induced changes in market structure and the BCCT's impacts.

This paper is also related to the large literature on environmental regulation and market structure. Numerous papers in this area have focused on manufacturing industries, showing that regulation can decrease output, increase exit, and/or decrease entry (List et al., 2003; Dean et al., 2000; Becker and Henderson, 2000; Pashigian, 1984; Greenstone, 2002). Studies suggest that average productivity can increase because inefficient plants are more likely to exit and entering plants tend to be more efficient. For surviving firms, diverting resources to regulatory compliance can decrease productivity, but upgrading production technology can increase productivity. Berman and Bui (2001) show that regulatory changes to oil refineries in California led to productivity increases. Abito (2018) provides evidence that

[6] Murray and Rivers (2015) provide a review of early work in this area.

price regulations on U.S. electric utilities led to lower fuel efficiency.

In gasoline markets, Carranza et al. (2015) study the impact of price floors on retail gasoline markets in Quebec, Canada, and Anderson and Johnson (1999) study the effect of sales-below-cost laws on retail gasoline margins in the United States. Eckert and West (2005) study retail station rationalization (in the Toronto area), and Eckert and West (2006) study the response of incumbent stations following a new entrant. One paper that looks at fuel tax passthrough with concentrated firms, though not in the retail gasoline market, is Miller et al. (2017). They study the Portland cement industry and find almost complete passthrough of fuel cost changes.

Two closely related papers are Ryan (2012), and Fowlie et al. (2016). Ryan (2012) estimates a dynamic model of competition between cement producers to evaluate the impact of a regulation that increased firms' sunk entry costs. Ryan's analysis shows that lower entry rates led to greater market power which increased the cost to consumers in the product market; he argues that these costs should be included in the overall cost of the policy. Fowlie et al. (2016) then use a similar model on the same dataset to estimate the impact of a number of counterfactual policies for pricing emissions. Their analysis accounts for market dynamics, including exit, in simulating the impact of carbon pricing on trade exposed cement markets. One difference between their setting and the one in this paper is that retail gasoline markets have minimal trade exposure. Given the costs associated with purchasing from unregulated markets, only retailers that are very close to BC boarders could be substituted for unregulated ones. Additionally, I construct a theoretical model which clearly illustrates the short-run and long-run impacts of the carbon tax and use a DiD estimation strategy to check the predictions of the theoretical model. My estimation strategy relies on the use of an unaffected control group as a baseline, while the procedure used by Fowlie et al. (2016) is to estimate a structural model and simulate counterfactual outcomes.

The remainder of this paper is organized as follows: section 2 presents an overview of the retail gasoline sector, and BC's carbon tax; section 3 introduces a theoretical model to characterize the expected impacts of the BCCT on retail gasoline markets; sections 4 and 5 describe the data and estimation procedure; results are discussed in section 6; and section 7 provides concluding remarks.

2 Industry Structure and the Carbon Tax

The retail gasoline industry in Canada is made up of many small geographic markets that vary in the degree of competition. Isolated rural markets may be local monopolies, while urban markets are likely to have more competitors. Two papers that characterize the industry's market sizes are Houde (2012), and Carranza et al. (2015). Houde (2012) accounts for commuting patterns in estimating retail gasoline demand in Quebec City and notes that the average consumer faces 10 stores within one minute of their optimal commuting route. Carranza et al. (2015) define neighbourhood retail gasoline markets using a clustering algorithm and find a median market size of 3 stations.

Given the sizes of retail gasoline markets, it should be expected that stations will hold market power. Moreover, research on price dynamics in retail gasoline markets suggests that market power does contribute to higher prices. For example, a number of researchers have identified asymmetric price changes in response to transitory marginal cost fluctuations (Verlinda, 2008; Deltas, 2008; Borenstein et al., 1997; Borenstein and Shepard, 1996; Duffy-Deno, 1996). Asymmetric pricing increases average retail margins over a given time period and is associated with market power at the station level.

Gasoline is first produced by a *refiner* and stored in holding tanks or transported to wholesale distribution terminals before being shipped (by truck) to retail outlets. Usually, a *marketer* purchases fuel from refiners and distributes it to retail outlets. The majority of marketers are not involved in upstream activities, but some of them are integrated companies that are also involved in refining, and a few are integrated with oil exploration/extraction companies. There are many different brands of gasoline that are sold at retail outlets.[7] Most outlets sell a refiner-owned brand (Petro-Canada, Shell or Esso for example), but many of these outlets are not owned by the same company that owns the brand. Refiner-owned brands can be marketed by multiple different companies, and there are various types of arrangements between retail outlets and the marketers that supply them. In some cases, the retail outlet is owned by the marketer, who also sets the price. However, the majority of retail outlets have direct control over pricing decisions.[8] For more detail on the structure of the Canadian oil and gas industry see Kent Group Ltd. (2017) and Conference Board of Canada (2001); these two reports provide much of the detail presented here.

Taxes make up a significant portion of the retail gasoline price. Canada's federal gasoline tax is 10¢/ltr and has not changed since 1995. Most provinces also charged per litre taxes during the sample period and a few regions had taxes that differed from the provincial level. Sales taxes are also applied to the retail price of gasoline when it is sold at the pump. Quebec is the only other province that had a carbon tax in place during the sample period.[9] As a result, I exclude Quebec from the control group.

2.1 Overview of BC's Gasoline Taxes

The BCCT started at \$10 per tonne of CO_2 equivalent emissions on July 1st 2008, and was scheduled to rise by \$5 each year until it reached \$30 per tonne on July 1st 2012. It was then held constant until April 1st 2018. For clear gasoline, the initial rate was 2.34¢/ltr. It increased to 3.51¢/ltr on July 1st 2009, there was an unscheduled decrease of 0.2¢/ltr on

[7]In 2016, there were 96 *brands* of gasoline in Canada (Kent Group Ltd., 2017).

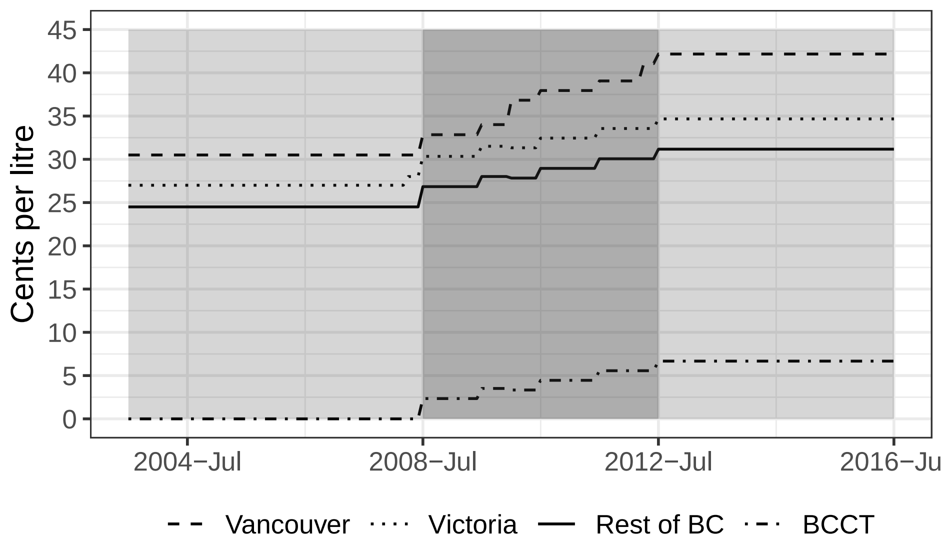
[8]58% of retail outlets have direct control over price as of 2001 (Conference Board of Canada, 2001)

[9]The Quebec carbon tax was held at a much lower level than the BCCT.

January 1st 2010, and then three more scheduled increases as it rose to 4.45¢/ltr on July 1st 2010, 5.56¢/ltr on July 1st 2011, and 6.67¢/ltr on July 1st 2012.

Gasoline sales in BC are subject to provincial, federal and regional taxes as well as retail sales taxes.[10] The two regions in BC where local gasoline tax differs from the provincial rate are Vancouver and Victoria.[11] Throughout BC gasoline taxes rose by 3.5¢/ltr in March 2003. For most of BC, this was the last gasoline tax change other than the BCCT, but in Victoria there was a small increase before the BCCT started (1¢/ltr in April 2008), and in Vancouver there was an increase of 5 ¢/ltr between the first and last BCCT changes (3¢/ltr in January 2010 and 2¢/ltr in April 2012). Including Vancouver and Victoria in the empirical analysis means that the results should be interpreted as the cumulative effect of these tax changes and the BCCT. I discuss this issue in more detail in the empirical section, and in the appendix I include a robustness check where I drop Vancouver and Victoria and the results are similar. BC's historical gasoline tax levels are shown in figure 1. The dark grey area in the middle corresponds to the BCCT's phase-in period.

Figure 1: Historical gasoline tax rates in British Columbia.



3 Theory

Gasoline companies often own stations in many different markets. However, individual stations compete against only a few rivals in small geographic markets. Given the size of retail

[10]Gasoline taxes are collected by the British Columbia Transportation Financing Authority throughout the province, the South Coast British Columbia Transportation Authority (TransLink) in the Vancouver area, and the British Columbia Transit Authority in the Victoria area.

[11]The only other area in Canada where gasoline taxes differ from the provincial rate is Montreal, Quebec.

markets, it is not likely that firms will have multiple retail outlets in the same market, thus cannibalization effects are expected to be small or non-existent. This allows me to investigate the impact of a tax by focusing on one representative market.

Suppose that n retail gasoline stations, indexed by $i \in \{1, ..., n\}$, simultaneously choose quantities q_i in order to maximize profits

$$\pi_i = (P - c_i - \tau)q_i - F_i. \tag{1}$$

c is the marginal cost of production, F is fixed cost, τ is a per unit tax, and the market demand curve is

$$P = P(Q) = A - BQ, \tag{2}$$

where $Q = \sum_i q_i$. Firm i's first order condition with respect to q_i is

$$\underbrace{A - BQ - Bq_i}_{mr_i} = c_i + \tau, \tag{3}$$

where the left hand side is firm i's marginal revenue (mr_i). Assuming that all firms maximize profits, we can add up equation (3) over firms and divide by n to get $A - \frac{n+1}{n}BQ^* = \bar{c} + \tau$, where $\bar{c} = \sum_i c_i$. Rearranging gives the equilibrium aggregate quantity of

$$Q^* = \frac{A - \bar{c} - \tau}{B}\frac{n}{n+1}. \tag{4}$$

It follows that the market price is

$$P^* = \frac{1}{n+1}A + \frac{n}{n+1}(\bar{c} + \tau), \tag{5}$$

firm i's output is

$$q_i^* = \frac{A - \tau - (n+1)c_i + n\bar{c}}{B(n+1)}, \tag{6}$$

and firm i's profit is

$$\pi_i^* = \left[\left(\frac{1}{n+1}\right)(A - \tau - (n+1)c_i + n\bar{c})\right]^2 \frac{1}{B} - F_i. \tag{7}$$

Allowing for free entry and exit, the long-run equilibrium number of firms is

$$n^* = n : \pi_i^* > 0 \;\; \forall i \in \{1, ..., n\} \;\text{ and }\; \pi_i^* \leq 0 \;\; \forall i \notin \{1, ..., n\}. \tag{8}$$

n^* is small enough for all active firms to make positive profit, but it is large enough that any potential entrant would make negative profit after entry. As shown in proposition 1, n^* is decreasing in the tax.

Proposition 1 (Long-run exit). *Denote the long-run equilibrium number of firms given tax level τ as n^*_τ, then*

$$\tau_2 > \tau_1 \Rightarrow n^*_{\tau_2} \leq n^*_{\tau_1}.$$

Proof. Note from equation (6), that positive output implies $A - \tau - (n+1)c_i + n\bar{c} > 0$, and from (7) that $\frac{\partial \pi_i^*}{\partial \tau} < 0$ whenever $A - \tau - (n+1)c_i + n\bar{c} > 0$. So, if $\tau_2 - \tau_1$ is large enough, then profit will become negative for some firm (or firms) causing exit. □

I first show the impact of the direct effect and the market-structure effect when firms are symmetric, which allows for a simple graphical illustration of the tax's impacts. Next, I show that allowing for heterogeneous firms gives qualitatively similar results. I derive a condition that ensures the impacts on prices and margins go in the same direction as in the symmetric firms model. The condition relates the size of the tax increase to demand parameters, market size, and fixed costs, and it is likely to be satisfied in retail gasoline markets.

3.1 Symmetric Firms

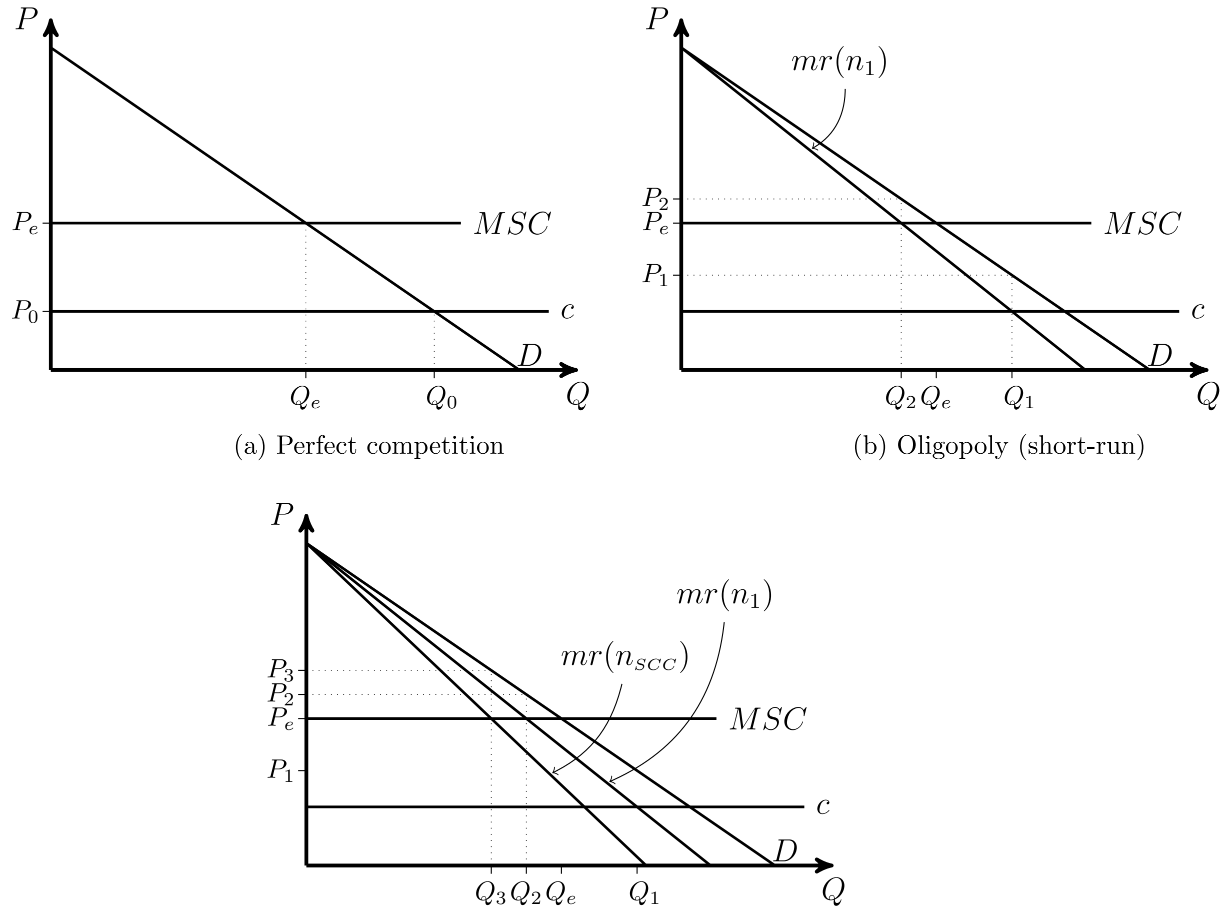
If firms are symmetric ($c_i = c$ and $F_i = F$), then quantities are $q_i = q = \frac{Q}{n}$ and equation (3) can be written as

$$\underbrace{A - B\frac{n+1}{n}Q}_{mr(n)} = c + \tau, \tag{9}$$

where $mr(n)$ is the marginal revenue with n firms that all produce Q/n. Equation (9) defines the equilibrium aggregate output Q^* given tax level τ and n firms. Two important points to note from equation (9) are: (i) an increase in the tax reduces equilibrium output; and (ii) a decrease in the number of firms makes $mr(n)$ steeper, which reduces equilibrium output.

Figure 2 outlines the direct and market-structure effects of a tax that equals the marginal damage of the externality. A perfectly competitive market is shown as a baseline in figure 2a. The market demand curve is D, and there is a negative externality so the marginal social cost of production (MSC) is greater than the marginal cost for firms (c). The difference $MSC - c$ is the marginal damage from the externality.[12] The unregulated competitive equilibrium at (Q_0, P_0) is inefficient, because Q_0 is too high; output in an efficient equilibrium must be Q_e. Setting a tax of $\tau_{SCC} = MSC - c$ would solve the problem and yield the socially efficient quantity Q_e at price $P_e = MSC$.

[12] In the case of carbon pollution, the marginal damage is commonly called the social cost of carbon.



(a) Perfect competition

(b) Oligopoly (short-run)

(c) Oligopoly (long-run)

Figure 2: Tax in an oligopoly market

Direct effect (oligopoly): Consider the oligopoly market in figure 2b, with n_1 firms and marginal revenue given by $mr(n_1)$. Without a tax, firms will choose quantity so that $mr(n_1) = c$, which results in the unregulated oligopoly outcome of (Q_1, P_1). Now suppose a regulator imposes a tax of τ_{SCC}, but the number of firms is held fixed in the short run. The direct effect will move the market equilibrium to (Q_2, P_2), because the taxed firms choose output to satisfy $mr(n_1) = \tau_{SCC} + c = MSC$. This causes an increase in the price, a decrease in the quantity, and a decrease in the margin (from $P_1 - c$ to $P_2 - MSC$).

Unlike in a competitive market, the direct effect of the tax τ_{SCC} in an oligopoly raises the price, and reduces the quantity, past the socially efficient level; the policy would overshoot its target. This is the same point made by Buchanan (1969) in the monopoly case, and it suggests that an optimal tax on an externality in an imperfectly-competitive market should be less than the marginal damage.

Market-structure effect: The same oligopoly market is shown in figure 2c. The market-structure effect moves the equilibrium from (Q_2, P_2) to (Q_3, P_3), because, following proposition 1, the long-run number of firms falls to n_{SCC} when the tax is τ_{SCC}.[13] Surviving firms gain market power, and set output so that $mr(n_{SCC}) = \tau_{SCC} + c = MSC$. This causes a further increase in price (reduction in aggregate quantity), and an increase in the margin relative to the short run.

The theoretical results provide predictions for prices, margins, and the number of stations that can be tested empirically. These predictions are stated in proposition 2. In the empirical section of this paper, I show that observed patterns in the data are consistent with these predictions.

Proposition 2 (Theoretical predictions). *The short-run effects of the tax will be: (i) an increase in the price, and (ii) a decrease in the retail margin. The long-run effects of the tax will be: (i) a decrease in the number of firms, (ii) a further increase in the price, and (iii) an increase in the retail margin (compared to the short run).*

In the remainder of this section I characterize these predictions when firms are not symmetric. While firm heterogeneity adds complexity, it does not qualitatively change the predictions. In the appendix I show that the predictions are similar in a model of price setting firms and in a Cournot style model with upstream integration. I also describe the welfare maximizing tax with symmetric firms in the appendix.[14]

3.2 Heterogeneous Firms

In general, the direct effect of the tax is determined by the short run passthrough rate. As long as the aggregate demand curve is not perfectly inelastic, it will lead to higher price and lower output. However, the market-structure effect is determined by long-run changes in the number and composition of surviving firms, which means that differences between exiting and surviving firms are important.

Using subscripts to denote the number of firms and the tax level, the direct effect of an increase in taxes from τ_1 to τ_2 on the price is $P_{n,\tau_2} - P_{n,\tau_1}$, and the market-structure effect, if k firms exit in the long-run, is $P_{n-k,\tau_2} - P_{n,\tau_2}$. It is clear from equation (5), that the direct effect will increase price and lower margins. But, with firm asymmetry, we need to consider the characteristics of exiting firms in order to determine the market-structure effect. Without loss of generality, suppose that we start with n active firms and denote the sets of surviving and exiting firms respectively as $\{1, ..., n-k\}$ and $\{n-k+1, ..., n\}$. Then using

[13] n_{SCC} is the long-run equilibrium number of firms when the tax is τ_{SCC}, as defined in equation (8).

[14] In some cases, increasing the tax even when $Q < Q_e$ can increase welfare because the long-run decrease in firms is also associated with a reduction in total fixed costs, which total nF. The increase in market power has a negative effect on welfare if and only if $Q > Q_e$, but the reduction in total fixed cost always has a positive effect on welfare.

equation (5) the change in price when k firms exit can be written as

$$P^*_{n-k,\tau} - P^*_{n,\tau} = \frac{1}{n+1}\left[\left(\frac{k}{n-k+1}\right)(A-\tau+(n-k)\bar{c}_{n-k}) - k\bar{c}_k\right], \tag{10}$$

where $\bar{c}_{n-k} = \frac{1}{n-k}\sum_{i=1}^{n-k} c_i$ is the average marginal cost of surviving firms, and $\bar{c}_k = \frac{1}{k}\sum_{i=n-k+1}^{n} c_i$ is the average marginal cost of exiting firms. Notice that $P^*_{n-k,\tau} - P^*_{n,\tau}$ is decreasing in $\bar{c}_k$ and increasing in $\bar{c}_{n-k}$; if surviving firms have lower marginal cost than exiting firms, then the price increase due to the market-structure effect will be dampened by an increase in average productivity.

Proposition 3. *Exit increases equilibrium price ($P^*_{n-k,\tau} - P^*_{n,\tau} > 0$) if and only if*

$$\left(\frac{1}{n-k+1}\right)(A-\tau) + \left(\frac{n-k}{n-k+1}\right)\bar{c}_{n-k} > \bar{c}_k.$$

Proposition 3 follows directly from equation (10), and it says that, in order for the market-structure effect to increase price, the average marginal cost of exiting firms has to be less than a weighted average of consumers' *net of tax maximum willingness to pay* $(A-\tau)$ and the average marginal cost of surviving firms. It is natural to assume that firms with the lowest profits will exit first (the high cost ones), which suggests that the increase in productivity could actually lead to lower prices. However, exiting firms' costs can be bounded, relative to surviving firms' costs, by assuming that all firms make positive profits before the tax increase.

Lemma 1. *In a long-run equilibrium with tax level τ, and free entry and exit, positive profits for all active firms implies that*

$$\left(\frac{A-\tau}{n-k+1}\right) + \left(\frac{n-k}{n-k+1}\right)\bar{c}_{n-k} - \left(\frac{n+1}{n-k+1}\right)\frac{1}{k}\sum_{i=n-k+1}^{n}\sqrt{BF_i} \geq \bar{c}_k.$$

Proof. Plug $n\bar{c} = (n-k)\bar{c}_{n-k} + k\bar{c}_k$ into the profit function from equation (7), and simplify $\pi^*_i \geq 0$ to get

$$A - \tau + (n-k)\bar{c}_{n-k} - (n+1)\sqrt{BF_i} \geq (n+1)c_i - k\bar{c}_k.$$

Averaging over the k firms in $\{n-k+1, ..., n\}$ gives

$$A - \tau + (n-k)\bar{c}_{n-k} - (n+1)\tfrac{1}{k}\textstyle\sum_{i=n-k+1}^{n}\sqrt{BF_i} \geq (n+1)\bar{c}_k - k\bar{c}_k,$$

and dividing by $n-k+1$ gives the result. $\square$

Proposition 4. *Starting from a long-run equilibrium with n^* firms, as in* (8)*, and tax level τ_1, if increasing the tax level to $\tau_2 > \tau_1$ causes the k firms indexed by $\{n^* - k + 1, ..., n^*\}$ to exit then*

$$\frac{n^* + 1}{k} \sum_{i=n^*-k+1}^{n^*} \sqrt{BF_i} > \tau_2 - \tau_1 \qquad \Rightarrow \qquad P^*_{n^*-k} - P^*_{n^*} > 0.$$

Proof. Note that lemma 1 implies proposition 3 if

$$\left(\tfrac{A-\tau_2}{n-k+1}\right) + \left(\tfrac{n-k}{n-k+1}\right) \bar{c}_{n-k} > \left(\tfrac{A-\tau_1}{n-k+1}\right) + \left(\tfrac{n-k}{n-k+1}\right) \bar{c}_{n-k} - \left(\tfrac{n+1}{n-k+1}\right) \tfrac{1}{k} \textstyle\sum_{i=n-k+1}^{n} \sqrt{BF_i}.$$

The left hand side of this expression comes from plugging τ_2 into proposition 3, and the right hand side is from plugging τ_1 into lemma 1. Simplifying gives $\frac{n^*+1}{k} \sum_{i=n^*-k+1}^{n^*} \sqrt{BF_i} > \tau_2 - \tau_1$. □

The intuition behind proposition 4 is that the market-structure effect will increase prices as long as demand is not *too* elastic and/or fixed cost are not *too* small relative to the tax increase. In the case of gasoline retailing, fixed costs are much larger than the per litre price of gasoline, and hence the per litre tax, so exit should be expected to increase price, even with heterogeneous firms.

4 Data

For the empirical analysis I construct two panel datasets. In the first, the unit of observation is a Canadian city in a given month and the outcomes of interest are retail gasoline prices and margins; these data are from KENT Marketing Ltd. I calculate retail margins as the net of tax retail price minus the wholesale price. Some cities in the sample have retail outlets, but do not have a wholesale terminal and, as a result, do not have wholesale prices. To calculate retail margins for these cities, I match each city without wholesale prices to the closest city with wholesale prices, but I limit the maximum distance to 300 kilometers apart.

The second dataset uses information from Statistics Canada's Business Register program, which tracks the number of establishments by North American Industry Classification System (NAICS). The cross sectional unit is a Canadian census division, and for each geographic unit I observe the number of businesses by industry twice per year.[15,16] The outcome of interest is the number of gasoline stations and I use business counts for other industry groups as control variables.

I use data from four Canadian provinces as a non-BC control group (Alberta, Ontario, Nova Scotia and Saskatchewan). I restrict the control group to just these four Canadian

[15] June and December are the two reference months for the Business Register program.

[16] Industry groups are at the 6 digit NAICS level.

Table 1: Summary Statistics

Province		Stations per census division		Retail price (¢/ltr)		Retail margin (¢/ltr)	
		Pre	Post	Pre	Post	Pre	Post
British Columbia	Mean	49.76	43.91	108.47	118.44	8.32	7.45
	St. dev	79.13	66.52	11.32	14.51	2.99	3.61
	Obs.	156	390	207	576	144	384
Ontario	Mean	57.66	53.64	101.11	114.06	5.47	6.87
	St. dev	53.68	50.77	11.76	16.92	3.11	3.37
	Obs.	192	480	477	1344	447	1344
Nova Scotia	Mean	21.82	22.18	109.93	117.61	8.56	8.94
	St. dev	20.02	21.82	10.87	16.77	1.51	1.47
	Obs.	96	240	198	576	198	576
Alberta	Mean	78.82	76.43	98.04	102.26	7.27	7.53
	St. dev	112.11	106.42	12.15	13.64	2.58	2.53
	Obs.	96	240	171	480	171	480
Saskatchewan	Mean	29.68	29.55	105.13	110.59	8.62	10.08
	St. dev	28.37	26.81	11.71	14.47	2.03	2.48
	Obs.	96	240	108	288	108	288

Notes: The pre period is July 2005 through June 2008. The post period is July 2008 through June 2016.

provinces, because the other provinces experienced a number of gasoline tax changes during the sample period. Restricting the control group to these four provinces allows me to define a pre-treatment period in which no gasoline tax changes took place in any of the control group provinces. However, the results are similar when including other Canadian provinces in the control group.[17] Of the four control provinces, only Alberta had a small change in gasoline tax in the post-treatment period, but not until March of 2015, almost three years after the BCCT reached its full level.[18] I observe retail prices and margins for 34 and 26 cities respectively (6 and 4 of these are in British Columbia), and I observe business counts for 106 census divisions (26 in British Columbia). Summary statistics for station counts, prices, and margins are shown in table 1, which splits the sample into pre-BCCT (July 2005 through June 2008) and post-BCCT (July 2008 through June 2016).

[17]Results with all Canadian provinces except Quebec are shown in the appendix. I exclude Quebec because it is the only other province that introduced a carbon tax during the sample period.

[18]Dropping Alberta after March 2015 does not qualitatively change the results. The results without Alberta are shown in section E of the appendix.

5 Empirical Model

My empirical approach is based on comparing market outcomes in BC with outcomes in the non-BC control group, and estimating short-run and long-run changes relative to a common base period. Specifically, I use Difference-in-Difference (DiD) regressions to estimate the impact of the BCCT on retail prices, retail margins, and the number of gasoline stations. My estimating equation is

$$y_{gt} = \alpha_0 + \gamma_t + \gamma_g + X_{gt}\beta + \delta \times \mathtt{I}(t \in \hat{T} \text{ and } g \in \text{BC}) + \epsilon_{gt}, \tag{11}$$

where y_{gt} is one of the outcome variables, g denotes the geographical unit, and t denotes the time period. When the number of gasoline stations is the outcome variable, g is the CD, and t is the biannual reference month (June or December). For the other outcome variables (prices and margins), g is the city, and t is the month. $\mathtt{I}(\cdot)$ is the indicator function, $\hat{T}$ denotes the treatment period, BC is the treatment group, and ϵ_{gt} is an idiosyncratic error term. The parameter δ estimates the impact of the BCCT on the outcome variable. X_{gt} is a vector of controls. Including controls means that δ can be interpreted as the impact of the BCCT net of any changes due to the control variables. I estimate equation (11) by OLS, and cluster standard errors at the geographical unit (either CD or city).

For the retail price and margin equations, I include controls for the log of the value of building permits, the average wage for retail employees, and the unemployment rate.[19] Building permits and the unemployment rate are included to account for demand side shocks, while the retail wage will account for supply side shocks. In the retail price equation, I also include controls for the wholesale price and other taxes. Other taxes are made up of gasoline taxes, excluding the BCCT, and sales taxes. Since sales taxes are a percentage of the final retail price, fluctuations in the price cause temporary changes in the tax amount. Wholesale price and other taxes account for changes in retailer costs and have significant explanatory power over retail prices.

For the number of gasoline stations equation, I include controls for the number of businesses in other industry groups (6 digit NAICS groups). I select the NAICS control groups using a lasso regression in which the shrinkage parameter is chosen by 10 fold cross-validation.[20] I also exclude some sectors that are likely to be directly affected by the carbon tax (automobile and other fuel and gas industries). The selected control groups are shown in table D1 of the appendix.

In order to increase similarity between BC and the control group census divisions, I create

[19] The value of building permits and the unemployment rate are measured at the city level for most cities, but not for all. I use the provincial average for cities without measurements. The average wage for retail employees is recorded at the provincial level.

[20] The shrinkage parameter is chosen as the largest value such that the cross validation error is within 1 standard error of its minimum.

a matched sample based on the number of gasoline stations per capita. Specifically, for every control group census division, I calculate the percentage distance of stations per capita from each BC census division. Then, I remove control census divisions that are not in the top 10% match for at least one of the BC census divisions. Table 2 shows summary statistics for the number of stations per 10,000 persons during the pre-treatment period in BC, the matched control group, and the unmatched control group.

Table 2: Stations per 10,000 persons

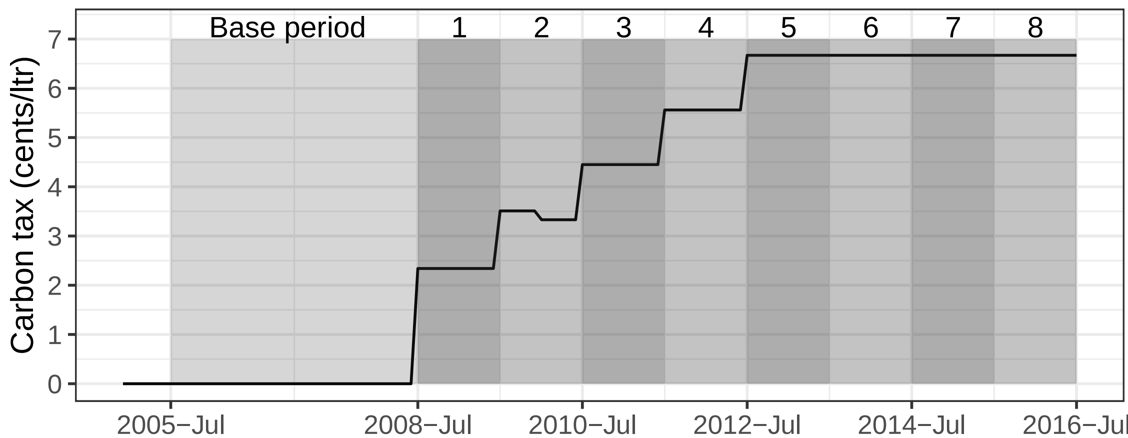
	Obs.	Mean	Min	Max	St. dev.
British Columbia	156	5.218	1.566	12.870	2.068
Controls (matched)	480	5.075	1.659	13.106	2.225
Controls (unmatched)	1,356	5.126	0	15.961	2.405

I use three years before the start of the BCCT as the pre-treatment base period, and I estimate the DiD model using eight separate post-treatment periods.[21] Each post-treatment period is one year in length and starts in July, the month that tax changes took place. The reason for not using only two post-treatment periods (one for the short run and one for the long run) is that choosing the cut-off between them would be arbitrary. By using more post-treatment periods, the estimated treatment effects from each post-treatment period can be compared with the theoretical model and used to determine when/if the transition from short run to long run occurs. Increasing the number of post-treatment periods reduces their duration so the cut-off can be determined more accurately, but it lowers estimation efficiency by reducing the number of observations in each period. Also, since the BCCT was introduced in stages between 2008 and 2012, using eight one-year post-treatment periods means that they align nicely with the scheduled carbon tax increases. Figure 3 shows the base and post-treatment periods along with the BCCT level.

The fact that the BCCT was introduced in stages complicates the interpretation of short-run and long-run effects because the magnitude of the carbon tax is inconsistent across post-treatment periods. However, because the last tax increase was at the start of period five, differences in the estimates for periods five through eight can be attributed to differences in the length of time since treatment. One way to think of the BCCT's introduction is as the arrival of a wave with the trough in the base period and the crest at the start of the fifth post-treatment period. Starting from the wave's crest (the last tax increase), we can track how the BCCT's impacts change over time and compare these changes with the theory.

[21] As noted previously, the BCCT was announced only 5 months before it was implemented so anticipatory behaviour in the pre-treatment period is not expected. However, I also estimate the model excluding the six months before the BCCT from the pre-treatment period (these results are shown in section E of the appendix).

Figure 3: Pre- and post-treatment periods



Following the theoretical model from section 3, the direct effect should increase retail prices and decrease retail margins in the short run, while the market-structure effect should increase retail prices, increase retail margins, and decrease the number of stations in the long run. Overall, the long-run effect is a combination of the direct and market-structure effects, so the retail margin in the long run should be higher than in the short run, but it could still be lower than the baseline level. Given the wave-like introduction of the BCCT, we may consider period five to be dominated by short-run effects, due its temporal proximity to the crest. But, periods six, seven, and eight have no contemporaneous effect of a carbon tax change and are successively farther from the crest, so the impact of the market-structure effect should grow over these periods. This does not rule out a reduction in the number of stations in or before period five, but it suggests that the transition between periods five and eight should be characterized by a decrease in the number of stations, an increase in the retail price, and an increase in the retail margin.

Another point to consider is the fact that Vancouver and Victoria had regional gasoline tax changes near/during the base period. As noted before, this affects interpretation of the results. The parameter δ captures the average change in outcome y in BC but includes the effect of the additional tax change in Vancouver and Victoria. This means that δ could overestimate the impact of the BCCT alone. My reason for including these cities is to reduce bias in the estimated standard errors that could could arise from having fewer treated units. However, I perform a robustness check where I exclude Vancouver and Victoria, and the results are similar in terms of both magnitude and statistical significance (results without Vancouver Victoria are shown in section E of the appendix). Moreover, the results with Vancouver and Victoria still illustrate the mechanism by which the increase in gasoline taxes drives some stations out of the market and leads to greater long-run passthrough.

5.1 Identification

Following a potential outcomes framework, I define the average treatment effect (ATE) on units in group G as

$$ATE(G) \equiv \sum_{g \in G} \left[\sum_{t \in \hat{T}} y_{gt}^1 - \sum_{s \notin \hat{T}} y_{gs}^0 \right], \tag{12}$$

where the superscript indicates whether or not the unit g received treatment in the treatment period (1 indicates treatment in $\hat{T}$, 0 indicates no treatment). Of course, we do not observe BC without the treatment in the post-treatment period ($y_{gt}^0 | t \in \hat{T}, g \in BC$) or the control group with the treatment in the treatment period ($y_{gt}^1 | t \in \hat{T}, g \notin BC$), so we cannot calculate the quantity in (12). However, the parameter δ is an unbiased estimator of $ATE(BC)$ if, in addition to the standard OLS assumptions, a *parallel trends* assumption is also satisfied. Formally, this assumptions can be written as

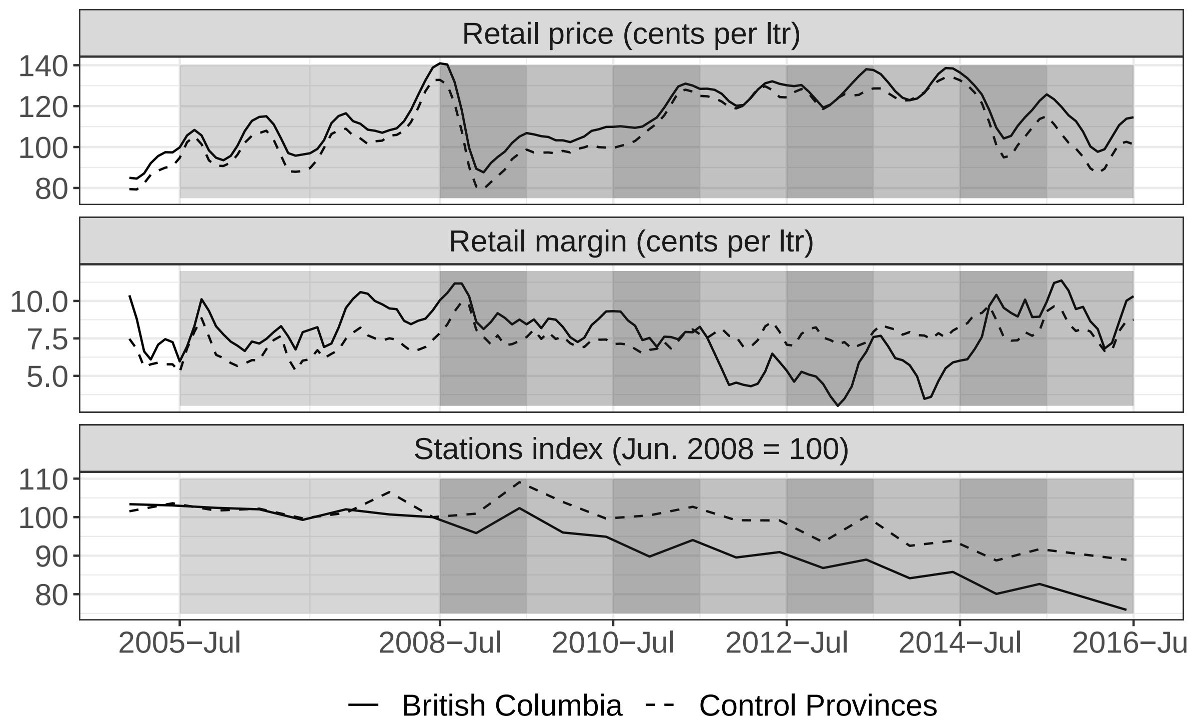
$$E(y_{gt}^0 - y_{gt'}^0 | t \in \hat{T}, t' \notin \hat{T}, g \in BC) = E(y_{g't}^0 - y_{g't'}^0 | t \in \hat{T}, t' \notin \hat{T}, g' \notin BC). \tag{13}$$

The parallel trends assumptions states that in the absence of treatment, both the treatment group and the control group would have followed the same trend. One way to check that this assumption holds is to compare trends in the pre-treatment period. Figure 4 shows time trends for the outcome variables over the sample period. The pre-treatment trends in BC are similar to the average over the control provinces. This suggests that the control provinces will act as a good counterfactual for the outcome in BC in lieu of the policy change.

The retail margin in BC declines declines initially, but then goes back up in later post-treatment periods. Also, the number of stations decreases in BC relative to the control provinces and the difference between the two groups grows over time. This is consistent with higher cost causing lower short-run profits, but greater long-run revenue due to less competition. However, in figure 4, stations in BC start to fall before the retail margin hits its low point. One possibility is that this is due to changes in the control variables that are unrelated to the policy change; including the NAICS group controls will account for this issue. Including the controls means that the DiD coefficient is interpreted as the impact of the BCCT net of any changes due to the control variables. To visualize this, I plot the *residualized* number of stations in BC and averaged over the control provinces in figure 5.[22] The residualized values show the change in the number of stations that is not attributed to changes in controls. The pre-treatment time trends remain similar across groups, but now the post-treatment trends are in line with the theoretical model (the decrease in stations occurs in the long run).

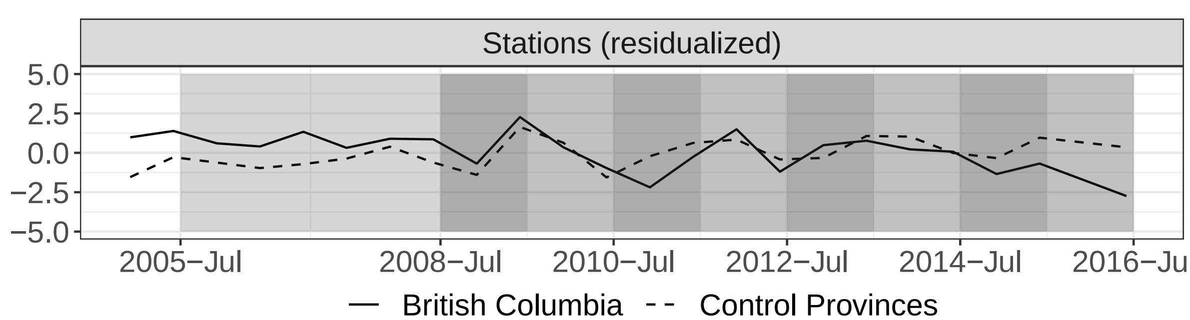
[22] The residualized values are the predicted error terms from a regression of the number of stations on time fixed effects, census division fixed effects, and the NAICS group controls. The regression uses the full sample for control provinces but restricts BC observations to those before the BCCT was introduced.

Figure 4: Outcome variable trends



Notes: The retail price and margin are shown in three month rolling mean due to volatility of the raw data. The number of stations are shown as indexes in order to compare values in BC with the Control provinces.

Figure 5: Station count trends (residualized)

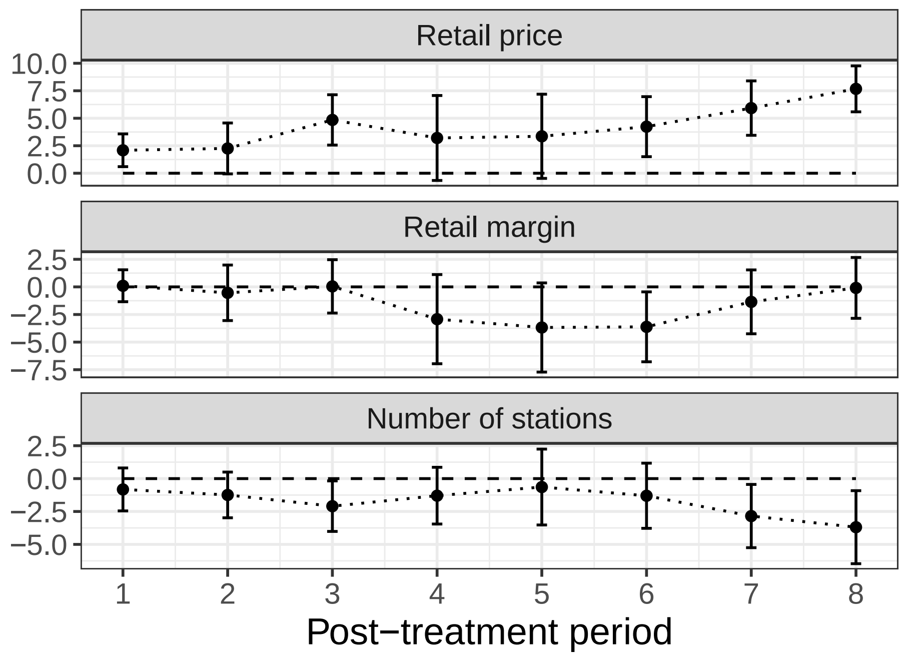


Notes: Residualized values for the number of stations in BC and averaged over the control provinces.

6 Results

DiD estimates for prices, margins, and the number of stations are shown in tables 3, 4, and 5 respectively; the columns correspond to the eight post-treatment periods. All regressions include both geographic unit and time period fixed effects. The NAICS group controls are not shown in the number of station regressions to save space. All the DiD estimates are summarized in figure 6.

Figure 6: DiD estimates of δ



Notes: The error bounds are 95% confidence intervals with standard errors clustered by geographic unit.

There are a number of important points to note in figure 6. First, the BCCT has a positive impact on the retail price and the magnitude is increasing over time. The impact on the retail price continues to rise in post-treatment periods 6, 7, and 8 even though there were no tax increases in these periods. Second, the retail margin begins to fall in period 4, and stays low until period 7 where it starts to return to the pre-BCCT level. Third, the BCCT has no significant impact on the number of stations in the short run, but has a negative impact on the number of stations in periods 7 and 8. These results are consistent with the theoretical model from section 3.

Following the theory, it is expected that the retail price increases by less than the tax in the short run, and the retail margin falls. In the long run, this causes stations to exit, which further increases retail price and raises margins above their short-run level. The low point for the retail margin is in periods 5 and 6 where the DiD estimates show decreases of 3.68¢/ltr and 3.62¢/ltr respectively. This is almost a 50% decrease in the retail margin, which averaged 8.32¢/ltr during the pre-treatment period in BC. Then, following the low point of the retail margin, the BCCT starts to have a significant effect on the number of stations. In periods 7 and 8, when the retail margin returns to pre-BCCT levels, the DiD estimates show an average loss of 2.85 and 3.69 stations per treated census division. Respectively, these represent a 5.73 % and 7.42 % decrease in the number of stations in BC relative to the base period. Moreover, in period 8, the DiD estimate for the long-run increase in the retail price in BC is 7.68¢/ltr, which is larger than the short-run price increase. To test the significance of this difference, I compare the period with the last tax increase (period 5) with the last period (period 8). The one-tail hypothesis test that the latter period's price increase is larger yields a p-value of 0.026.[23] The long-run price increase is also larger than the tax of 6.67¢/ltr, though the difference is not statistically significant.[24]

While the empirical estimates do not show an immediate decrease in the retail margin, they do show that it starts to fall as the BCCT reaches its highest level, and it goes back up as stations exit the market. Moreover, the timing of the exit and the increase in margins is consistent with the story that lower profits due to incomplete passthrough caused stations to exit. These results suggest that the market-structure effect contributed to the long-run price increase.

Table 3: Difference-in-Difference estimates for retail price

	Dependent variable:							
	Retail price (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	2.088***	2.256*	4.850***	3.206	3.359*	4.235***	5.924***	7.676***
	(0.760)	(1.181)	(1.168)	(1.971)	(1.953)	(1.392)	(1.262)	(1.066)
log(building permits)	0.160	0.084	0.358***	0.486**	0.164	0.292**	−0.011	−0.152
	(0.112)	(0.094)	(0.127)	(0.227)	(0.202)	(0.132)	(0.125)	(0.148)
Retail wage	0.380***	0.309**	0.379***	0.317	0.120	0.243	−0.118	0.372***
	(0.167)	(0.148)	(0.110)	(0.196)	(0.135)	(0.152)	(0.195)	(0.128)
Unemployment rate	−0.064	−0.086	−0.137	−0.235*	−0.313**	−0.180	−0.283**	−0.014
	(0.112)	(0.111)	(0.124)	(0.141)	(0.160)	(0.132)	(0.131)	(0.169)
Other taxes	1.732***	1.920***	1.148***	1.187***	1.180***	1.304***	1.221***	1.392***
	(0.163)	(0.273)	(0.082)	(0.084)	(0.089)	(0.073)	(0.082)	(0.108)
Wholesale price	0.994	0.967***	0.937***	0.947***	0.939***	0.958***	0.965***	0.974***
	(0.034)	(0.034)	(0.037)	(0.036)	(0.037)	(0.041)	(0.035)	(0.031)
Constant	−19.594***	−21.323***	−1.147	−1.121	3.551	−3.211	6.052	−9.831***
	(4.464)	(6.956)	(3.490)	(4.482)	(4.001)	(4.048)	(4.665)	(3.677)
Observations	1,452	1,452	1,452	1,446	1,452	1,449	1,452	1,452
R^2	0.990	0.981	0.984	0.986	0.985	0.990	0.984	0.979

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail price in BC during the base period is 108.47. *p<0.1; **p<0.05; ***p<0.01.

[23]The long-run price increase in period 8 is also significantly larger than the estimated price increases in periods one through four. The respective p-values for these tests are: 0.00001, 0.0003, 0.037, and 0.023.

[24]The p-value for the one-tail test that the retail price in period 8 is larger than the BCCT is 0.173.

Table 4: Difference-in-Difference estimates for retail margin

	Dependent variable:							
	Retail margin (¢/ltr)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	0.102	−0.535	0.047	−2.921	−3.676*	−3.618**	−1.354	−0.091
	(0.737)	(1.283)	(1.233)	(2.061)	(2.061)	(1.615)	(1.476)	(1.406)
log(building permits)	0.163	0.192*	0.399***	0.524**	0.153	0.349**	−0.022	−0.122
	(0.147)	(0.101)	(0.126)	(0.234)	(0.204)	(0.167)	(0.156)	(0.180)
Retail wage	0.542***	0.299*	0.532***	0.335	0.180	−0.012	−0.104	0.224
	(0.236)	(0.172)	(0.134)	(0.214)	(0.148)	(0.182)	(0.242)	(0.162)
Unemployment rate	−0.060	−0.054	−0.106	−0.184	−0.266	−0.143	−0.323*	−0.123
	(0.125)	(0.132)	(0.139)	(0.137)	(0.200)	(0.168)	(0.187)	(0.222)
Constant	−5.353	−0.617	−4.668	−0.502	2.686	6.346*	9.037*	1.694
	(4.967)	(3.495)	(2.897)	(4.281)	(3.340)	(3.563)	(5.066)	(3.805)
Observations	1,176	1,176	1,176	1,172	1,176	1,174	1,176	1,172
R^2	0.703	0.667	0.653	0.636	0.649	0.646	0.648	0.640

Notes: Standard errors are clustered at the city level. All regressions include a full set of city and time period dummies. The average retail margin in BC during the base period is 8.32. *p<0.1; **p<0.05; ***p<0.01..

Table 5: Difference-in-Difference estimates for number of stations

	Dependent variable:							
	Stations							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post treatment in BC (δ)	−0.823	−1.242	−2.095**	−1.297	−0.641	−1.303	−2.847**	−3.693***
	(0.832)	(0.886)	(0.980)	(1.100)	(1.471)	(1.263)	(1.226)	(1.416)
Constant	6.922***	8.070***	7.861***	6.565***	4.949***	5.748***	5.440***	5.571***
	(1.004)	(0.971)	(1.035)	(0.983)	(1.104)	(1.156)	(1.196)	(1.197)
NAICS group Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	848	848	848	848	848	848	848	742
R^2	0.998	0.998	0.998	0.998	0.997	0.997	0.997	0.997

Notes: Standard errors are clustered at the census division level. All regressions include a full set of census division and time period dummies. The average number of stations in a BC census division during the base period is 49.76. *p<0.1; **p<0.05; ***p<0.01.

7 Conclusion

In this paper I use a policy change in British Columbia to study the difference between short-run and long-run impacts of a carbon tax on retail gasoline markets. I show that the tax has both a direct effect (in the short-run) and market-structure effect (in the long-run). The direct effect increases the marginal cost of gasoline retailing, which, in turn, raises the retail price. The market-structure effect reduces the number of stations due to lower short-run profits. This increases market power leading to a secondary price increase, but may also increase average productivity of surviving firms, which dampens the secondary price increase. The short-run impact on price is a result of the direct effect while the long-run impact is caused by the combination of both the direct and the market-structure effects.

In British Columbia's case, incomplete passthrough of the BCCT in the short-run led to a higher retail price, but a lower retail margin. However, in the long-run the BCCT led to a 7.42% decrease in the number of stations and a 7.68¢/ltr increase in the retail price in BC. This is significantly larger than the short-run price increase, which is estimated at 3.36¢/ltr in the year following the last tax increase. The long-run price increase is also larger than the tax of 6.67¢/ltr, but the difference is not statistically significant. These results suggest that the market-structure effect was an important factor for the impact of the BCCT on retail gasoline markets.

This paper highlights one of the complications with setting Pigouvian taxes in imperfectly competitive markets by showing that policy induced changes in market structure can lead to larger price increases in the long-run than in the short-run. Taken on its own, the increase in market power due to a tax-induced reduction in firms means that a dynamic model implies a lower optimal tax than a static model, and it suggests that the tax should be lower than the social cost of carbon. However, the fact that the market-structure effect led to greater long-run price increases in BC's retail gasoline markets does not necessarily mean that the tax should be lower than the social cost of carbon. This is because the role of market power is not the only factor to consider. One argument in favour of higher carbon pricing is that it can stimulate productivity growth. For example, improvements in pollution abatement or production technology are likely to be expedited in the face of higher carbon pricing or more stringent regulation. These other factors are also important, though they are not the focus of this paper.

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Appendix

A Welfare maximizing tax (symmetric firms)

When market price is above the MSC, increasing market power has a negative welfare effect. But, fewer firms also require fewer fixed cost payments, which improves production efficiency. An optimal tax in this setting maximizes the total surplus function

$$\begin{aligned} TS(n,\tau) &= \underbrace{\int_0^{Q^*} (A - Bz)dz}_{\text{total benefits}} - \underbrace{\left[(c+\epsilon)Q^* + nF\right]}_{\text{total costs}} \\ &= \frac{1}{B}\frac{n}{n+1}\left[(A-c-\epsilon)(A-c-\tau) - \frac{1}{2}\left(\frac{n}{n+1}\right)(A-c-\tau)^2\right] - nF \ , \end{aligned} \tag{A1}$$

where ϵ is the marginal damage from the externality. Note that $\frac{\partial^2 TS}{\partial \tau^2} = -\frac{1}{B}\left(\frac{n}{n+1}\right)^2$, so for fixed n, TS is a smooth concave function of τ. If changes in n were ignored, then total surplus would be maximized at $\tau = \frac{n+1}{n}\epsilon - \frac{1}{n}(A-c) < \epsilon$.[25] But, the fact that n^* is a step function in the tax level means that market surplus has discrete jumps when $\frac{A-c-\tau}{\sqrt{BF}} - 1$ takes integer values. An example of this function is shown in figure A1.

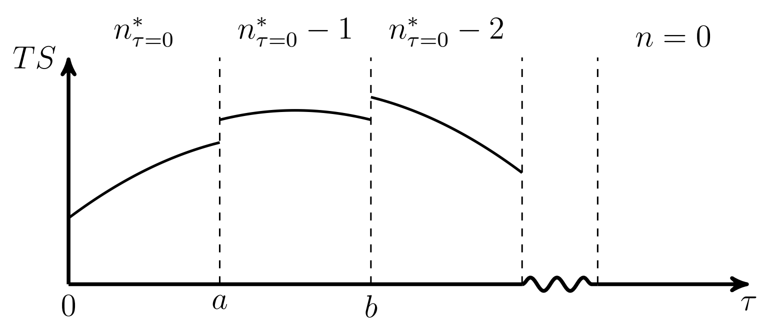


Figure A1: Total surplus function

To describe the direction of the jumps as a function of τ it is useful to let $\overline{\tau}(n) \equiv (A-c) - (n+1)\sqrt{BF}$ denote the upper bound on the tax that would satisfy n firms in the market. For example, $\overline{\tau}(n^*_{\tau=0}) = a$ in figure A1, and any $\tau \geq a$ implies that at least one firm would exit in the long-run.

Proposition 5. *The total surplus function in equation* (A1) *has a positive jump at* $\overline{\tau}(n)$ *if and only if* $\overline{\tau}(n) < \epsilon + n\sqrt{BF}$.

[25] The last inequality comes from the assumption that $A - c > \epsilon$. If $A - c < \epsilon$, then even at $Q = 0$ the marginal benefit from consumption is smaller than the marginal social cost.

Proof. Note that $\frac{\partial TS}{\partial n}|_{\tau=\overline{\tau}(n)} = \frac{1}{n+1}\left[(A-c-\epsilon)\sqrt{F/B}-(2n+1)F\right]$. Simplifying $\frac{\partial TS}{\partial n}|_{\tau=\overline{\tau}(n)} < 0$ gives $(A-c)-(n+1)\sqrt{BF} < \epsilon + n\sqrt{BF}$, where the left hand side is equal to $\overline{\tau}(n)$. □

Proposition 5 suggests that increasing τ may increase total surplus even if the partial $\frac{\partial TS}{\partial \tau}$ is less than zero. For example, consider point b in figure A1 where TS is decreasing in τ just to the left, but it jumps upwards at point b. An algorithm to find the optimal tax in this setting is to start with the equilibrium n for $\tau = 0$ and maximize TS on the interval $A-c-(n+2)\sqrt{BF} \leq \tau < A-c-(n+1)\sqrt{BF}$, then decrease n by one and repeat until $n = 1$ and choose the largest surplus from this set of intervals. The optimal tax, τ^*, solves

$$\max_{n\in\{1,\ldots,n^*_{\tau=0}\}} \left\{ \max_{\tau\in\left[\overline{\tau}(n+1),\overline{\tau}(n)\right)} TS(n,\tau) \right\}. \tag{A2}$$

B Differentiated product price competition

This section describes a retail gasoline market with stations setting prices rather than quantities. The model below draws from Weyl and Fabinger (2013) and Miller et al. (2017). Weyl and Fabinger (2013) present a theoretical analysis of tax incidence in a model of imperfect competition, and Miller et al. (2017) provide a detailed examination of passthrough using the Weyl and Fabinger (2013) framework.

Consider a market with n retail stations each with profit

$$\pi_i(\mathbf{p}) = q_i(\mathbf{p})p_i - c_i q_i(\mathbf{p}) - F_i \tag{B1}$$

p_i is the price set by firm i, $\mathbf{p}$ is the vector of prices for all firms c_i is i's marginal cost and F_i is i's fixed cost. Firm i's profit maximizing condition can be written as follows.

$$f_i(\mathbf{p}) \equiv p_i + \left(\frac{\partial q_i(\mathbf{p})}{\partial p_i}\right)^{-1} q_i(\mathbf{p}) - c_i = 0 \tag{B2}$$

If firms are faced with a per unit tax τ then their profit maximizing condition becomes

$$f_i(\mathbf{p}) - \tau = 0 \tag{B3}$$

Note that (B3) implicitly defines firm i's best response price as a function of its marginal cost, the tax, and the prices of other firms. Let $\mathbf{t}$ be a vector of length n with each element equal to τ and $\mathbf{f}(\mathbf{p}) = [f_1(\mathbf{p}), ..., f_n(\mathbf{p})]'$, then the market equilibrium with a tax can be written as

$$\mathbf{f}(\mathbf{p}) - \mathbf{t} = 0 \tag{B4}$$

Implicitly differentiating (B4) gives

$$\rho \equiv \frac{\partial \mathbf{p}}{\partial \mathbf{t}'} = \left(\frac{\partial \mathbf{f}(\mathbf{p})}{\partial \mathbf{p}'}\right)^{-1} = \begin{bmatrix} \rho_{11} & \cdots & \rho_{1n} \\ \vdots & & \vdots \\ \rho_{n1} & \cdots & \rho_{nn} \end{bmatrix} \tag{B5}$$

where ρ_{ij} is the effect on firm i's price of a change in tax to firm j. Note that ρ is a function of all firms prices' and costs. The total effect of a tax on firm i's equilibrium price is $\rho_i = \sum_{j=1}^{n} \rho_{ij}$.

Let $\mathbf{p}^*$ be the solution to (B4). The marginal effect of the tax on firm i's profits in equilibrium is

$$\frac{d\pi_i^*}{d\tau} = -q_i(\mathbf{p}^*)\left(\frac{\partial q_i(\mathbf{p}^*)}{\partial p_i^*}\right)^{-1} \sum_{j \neq i} \frac{\partial q_i(\mathbf{p}^*)}{\partial p_j^*}\rho_j - q_i(\mathbf{p}^*) \tag{B6}$$

Using the first order condition (B4), this can be rewritten as

$$\frac{d\pi_i^*}{d\tau} = -q_i(\mathbf{p}^*)\left(\frac{\partial q_i(\mathbf{p}^*)}{\partial p_i^*}\right)^{-1} \sum_{j \neq i} \frac{\partial q_i(\mathbf{p}^*)}{\partial p_j^*}\rho_j - q_i(\mathbf{p}^*)$$

so firm i's profit is decreasing in τ if

$$\sum_{j \neq i} \frac{\partial q_i(\mathbf{p}^*)}{\partial p_j^*}\rho_j < -\frac{\partial q_i(\mathbf{p}^*)}{\partial p_i^*} \tag{B7}$$

(B7) states that the impact of a tax increase via changes in rival firms' prices must be smaller in magnitude than the responsiveness of a firms demand to a change in its own price only.

C Two stages of production

This model follows the setups in Salinger (1988), Gaudet and Long (1996), and Neumann et al. (2005), but focuses on how changes in the tax, or the number of firms, impact prices. Consider a market with N^I integrated firms, N^R retail-only firms, and N^W wholesale-only firms. Let i denote an integrated firm, j a retail-only firm, and k a wholesale-only firm. Let q_i^I, and q_j^R be quantities in the retail market for the i^{th} integrated firm, and the j^{th} retail-only firm. Define x_i^I, and x_k^W as quantities in the wholesale market for the i^{th} integrated firm, and the k^{th} wholesale-only firm. Note that $x_i^I > 0$ represents sales of wholesale gasoline, and $x_i^I < 0$ represents purchases. Profit for the i^{th} integrated firm is

$$\pi_i^I = (P^R - c - \tau)q_i^I + (P^W - c - \tau)x_i^I - F_i^I \qquad i = 1, ..., N^I, \tag{C1}$$

profit for the k^{th} wholesale-only firm is

$$\pi_k^W = (P^W - c - \tau)x_k^W - F_k^W \qquad k = 1, ..., N^W, \tag{C2}$$

and profit for the j^{th} retail-only firm is

$$\pi_j^R = (P^R - P^W)q_j^R - F_j^R \qquad j = 1, ..., N^R, \tag{C3}$$

where c is the marginal cost of refining crude oil into gasoline and transporting it to the retail market, and τ is the amount of carbon tax. Suppose that fixed costs (F_i^I, F_k^W, F_j^R) are independent draws from type specific distributions. Denote these distributions as $(\mathcal{F}^I, \mathcal{F}^W, \mathcal{F}^R)$, then $F_i^I \sim \mathcal{F}^I, F_k^W \sim \mathcal{F}^W$ and, $F_j^R \sim \mathcal{F}^R$. The demand function in the retail market is

$$P^R = P^R(Q) = A - BQ \tag{C4}$$

with $Q = \left(\sum_i q_i^I + \sum_j q_j^R\right)$. P^W is the market price for wholesale gasoline.

In the first stage, integrated and wholesale-only firms respectively choose x_i^I and x_k^W. Then in the second stage integrated and retail-only firms respectively choose q_i^I, and q_j^R. Given the sequential nature of the game, it must be solved by backward induction. In stage 2, integrated firms and retail-only firms choose quantities q_i^I, and q_j^R conditional on P^W, c, τ, N^I, N^R and the retail market demand. Since the only heterogeneity within a firm type is in their fixed costs, each firm will select the same quantity as others of the same type. The equilibrium quantities are:

$$q_i^{I,*} = \frac{A - (N^R + 1)(c + \tau) + N^R P^W}{(N^I + N^R + 1)B} \tag{C5}$$

$$q_j^{R,*} = \frac{A - (N^I + 1)P^W + N^I(c + \tau)}{(N^I + N^R + 1)B} \tag{C6}$$

This is the standard Cournot outcome when N^I firms have marginal cost $(c + \tau)$, N^R firms have marginal cost P^W, and demand is given by (C4).

A retail-only firm's optimal choice of q_j^R can also be thought of as a demand function for wholesale gasoline given the price P^W. Since all retail-only firms are identical except for their fixed cost, we can aggregate (C6) into an aggregate demand for wholesale gasoline. By letting $X = \sum_{i=1}^{N^I} x_i^I + \sum_{k=1}^{N^W} x_k^W$ denote the net supply of wholesale gasoline available to retail-only firms, and imposing market clearing, the inverse demand function for wholesale gasoline can be written as

$$P^W = \frac{A + N^I(c + \tau)}{N^I + 1} - \frac{N^I + N^R + 1}{N^I + 1}\frac{B}{N^R}X \tag{C7}$$

In stage 1, integrated and wholesale-only firms account for the retail market outcomes when they set their quantities for wholesale gasoline. Plugging, (C5), (C6), and (C7) into the integrated and wholesale-only profit functions gives:

$$\pi_i^I = \left(\frac{1}{N^I+1}\right)^2 B\left(\frac{A-(c+\tau)}{B} - X\right)^2 \\ + \left(\frac{A-(c+\tau)}{N^I+1} - \frac{N^I+N^R+1}{N^I+1}\frac{B}{N^R}X\right)x_i^I - F_i^I \tag{C8}$$

$$\pi_k^W = \left(\frac{A-(c+\tau)}{N^I+1} - \frac{N^I+N^R+1}{N^I+1}\frac{B}{N^R}X\right)x_k^W - F_k^W \tag{C9}$$

The integrated and wholesale-only firms choose x_i^I, and x_k^W to respectively maximize (C8), and (C9). Equilibrium quantities solve the first order conditions

$$x_i^I = \frac{N^R(N^I-1)\frac{A-c}{B} - \left[(N^I+1)(N^I+N^R+1) - 2N^R\right]N^W x_k^W}{(N^I+1)^2(N^I+N^R+1) - 2N^R N^I} \tag{C10}$$

$$x_k^W = \frac{N^R\frac{A-c}{B} - N^I(N^I+N^R+1)x_i^I}{(N^I+N^R+1)(N^W+1)}. \tag{C11}$$

The resulting equilibrium quantities are

$$x_i^{I,*} = \alpha\frac{A-(c+\tau)}{B} \tag{C12}$$

$$x_k^{W,*} = \beta\frac{A-(c+\tau)}{B} \tag{C13}$$

where

$$\alpha = \left(\frac{N^R}{N^I+N^R+1}\right)\left[\frac{(N^I+N^R+1)(N^I-1) - 2(N^I+1)N^W}{(N^I+N^R+1)(N^I+1)(N^I+N^W+1) - 2N^I N^R}\right]$$

$$\beta = \frac{1}{N^W+1}\left[\frac{N^R}{N^I+N^R+1} - N^I\alpha\right].$$

$[A-(c+\tau)]/B$ is the perfectly competitive output; it is the amount that would be sold on the retail market when both the wholesale and retail markets are perfectly competitive. So, α and β are shares of the competitive output that integrated and wholesale-only firms provide to the wholesale market. For wholesale-only firms, this is always positive. But, integrated firms can either purchase or sell wholesale gasoline. By decreasing x_i^I, integrated firms can increase the wholesale price, which is the marginal cost of their retail-only competitors. In equilibrium, integrated firms' choice of x_i^I balances a trade off between their market share in the retail market on the one hand, and both their wholesale profit and retail marginal cost on the other hand. If the potential gain in market share is large enough, then they may even purchase some gasoline on the wholesale market. The condition for integrated firms to be purchasers of wholesale gasoline is $\alpha < 0$, which can be written as

$$(N^I + N^R + 1)(N^I - 1) - 2(N^I + 1)N^W < 0. \tag{C14}$$

When (C14) is satisfied, an integrated firm will produce some gasoline for itself and will purchase the remainder from wholesale only firms. Note from (C14) that for a given number of integrated firms, they are more likely to purchase wholesale gasoline if N^W is large or if N^R is small[26]

The aggregate equilibrium quantities can be written as

$$X = \lambda \frac{A - (c + \tau)}{B} \tag{C15}$$

$$Q = \frac{N^I + \lambda}{N^I + 1} \frac{A - (c + \tau)}{B}, \tag{C16}$$

where $\lambda = N^I \alpha + N^W \beta$ is the share of the perfectly competitive downstream output that retail-only firms purchase in the wholesale market.

The equilibrium prices are

$$P^W = \left(\frac{1 - \frac{N^I + N^R + 1}{N^R} \lambda}{N^I + 1} \right) A + \left(\frac{N^I + \frac{N^I + N^R + 1}{N^R} \lambda}{N^I + 1} \right) (c + \tau) \tag{C17}$$

$$P^R = \left(\frac{1 - \lambda}{N^I + 1} \right) A + \left(\frac{N^I + \lambda}{N^I + 1} \right) (c + \tau). \tag{C18}$$

It is easy to verify that when $N^I = 0$, the wholesale price is $P^W = \frac{1}{N^W + 1} A + \frac{N^W}{N^W + 1} c$, which is independent of N^R. In other words, without the presence of integrated firms, changes in retail market power would not affect the wholesale price.

The margin for a retail-only firm is

$$M^R = P^R - P^W, \tag{C19}$$

and the retail margin for an integrated firm is

$$M_I^R = P^R - (c + \tau). \tag{C20}$$

The outcomes in (C17)-(C20) are the key outcomes of interest. In the remainder of this section I describe how these outcomes change in the short- and long-run following a tax increase.

[26] The left hand side of (C14) is decreasing in N^W and increasing in N^R.

C.1 Impact of a tax on market outcomes

The direct effect of the tax is to increase the marginal cost of producing gasoline, so the short-run impact of the tax is determined by the derivatives of prices and margins with respect to τ. The change in the wholesale price is

$$\frac{\partial P^W}{\partial \tau} = \left(\frac{N^I + \frac{N^I + N^R + 1}{N^R} \lambda}{N^I + 1} \right). \tag{C21}$$

The change in the retail price is

$$\frac{\partial P^R}{\partial \tau} = \left(\frac{N^I + \lambda}{N^I + 1} \right). \tag{C22}$$

The change in the retail-only firms' margin is

$$\frac{\partial M^R}{\partial \tau} = -\frac{\lambda}{N^R}. \tag{C23}$$

The change in the integrated firms' retail margin is

$$\frac{\partial M_I^R}{\partial \tau} = -\left(\frac{1 - \lambda}{N^I + 1} \right). \tag{C24}$$

$\lambda \in (0, 1)$ implies that the wholesale price, P^W, and the retail price, P^R, are increasing in τ, while the retail-only firms' margin, M^R, and the retail margin for integrated firms, M_I^R, are decreasing in τ.

The market structure effect depends of the decision to exit when the tax is increased. Let $\bar{F}^R$ denote the break-even fixed cost for a retail-only firm.

$$\bar{F}^R = F_j^R : \pi_j^R = (P^R - P^W) q_j^R - F_j^R = 0. \tag{C25}$$

A retail-only firm makes a positive profit if its fixed cost is less than $\bar{F}^R$, and it makes a negative profit if its fixed cost is greater than $\bar{F}^R$. If $F_j^R > \bar{F}^R$, then firm j would exit in the long-run.[27] Also, suppose that an integrated firm's fixed cost is $F^I = F^R + F^W$ and let $\bar{F}_I^R$ denote the break-even fixed cost for an integrated firm's retail outlet.

$$\bar{F}_I^R = F_i^R : \pi_i^R = (P^R - c - \tau) q_i^R - F_i^R = 0. \tag{C26}$$

If a firm's fixed cost in the retail market is greater than $\bar{F}_I^R$, then the station would exit in the long-run. Since profits are decreasing in τ, $\bar{F}$ decreases when τ increases. Therefore, a higher tax will mean that the break-even fixed cost will decrease. In turn, stations with

[27] The firm will continue producing in the short-run as long as $(P^R - P^W) q_j^R > 0$.

high fixed cost may exit the market. To see the changes in market outcomes associated with retail outlets closing, I define the following functions.

$$\Delta^R(\theta) \equiv \theta(N^I, N^R + 1, N^W) - \theta(N^I, N^R, N^W) \tag{C27}$$
$$\Delta^R_I(\theta) \equiv \theta(N^I, N^R + 1, N^W - 1) - \theta(N^I, N^R, N^W). \tag{C28}$$

$\Delta^R(\theta)$ gives the impact on the variable θ when a retail-only station enters, and $\Delta^R_I(\theta)$ is the impact when a wholesale-only firm opens a retail station (becomes integrated). Alternatively, $-\Delta^R(\theta)$ is the effect of a retail-only station exiting, and $-\Delta^R_I(\theta)$ is the effect of an integrated firm closing their retail site only.

Analytic solutions for the signs of $\Delta^R(\cdot)$, and $\Delta^R_I(\cdot)$ are difficult to interpret so I present numerical results in section C.2 of the appendix. I evaluate the model for each point in the parameter space $\chi = \{(N^R, N^W, N^I) : N^R \in \{1, ..., 20\}, N^W \in \{0, ..., 20\}, N^I \in \{0, ..., 20\}\}$ with $c = 0$.[28] The numerical results shows that: (i) The wholesale price increases when retail sites close, $\Delta^R(P^W) < 0$ and $\Delta^R_I(P^W) < 0$ (see figures C5 and C6)[29]; (ii) The retail price increases when retail sites close, $\Delta^R(P^R) < 0$ and $\Delta^R_I(P^R) < 0$ (see figures C7 and C8); (iii) The retail margin increases when retail sites close, $\Delta^R(M^R) < 0$, $\Delta^R_I(M^R) < 0$, $\Delta^R(M^R_I) < 0$ and $\Delta^R_I(M^R_I) < 0$ (see figures C9, C10, C11 and C12). This is the market structure effect.

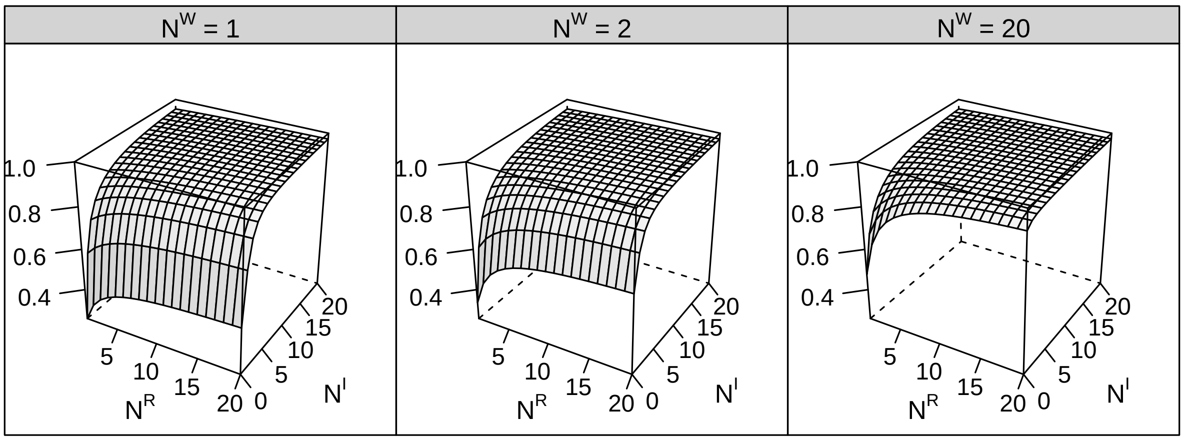
To summarize, the model predicts that in the short-run the impact of the tax is to raise prices in both wholesale and retail markets, and decrease retail margins; this is the direct effect of the tax change. However, in the long-run, the market structure effect will arise if the decrease in margins results in exit of stations from the retail market.

[28] I set $c = 0$ for simplicity, but the results are robust to $c > 0$.

[29] There are two exceptions to this result. The first is when $N^I = 0$. In this case, P^W does not change with N^R because the wholesale firms provide a quantity such that P^W is equal to the Cournot equilibrium with N^W firms in the downstream market. This allows their profit to approach the Cournot profit as the downstream market becomes more competitive; so $\Delta^R(P^W) = 0$ in this case. The second exception occurs when $(N^I, N^W) = (0, 1)$. In this case, when the wholesale firm integrates it will stop selling to retail-only firms and P^W becomes undefined, so $\Delta^R_I(P^W)$ is not defined here.

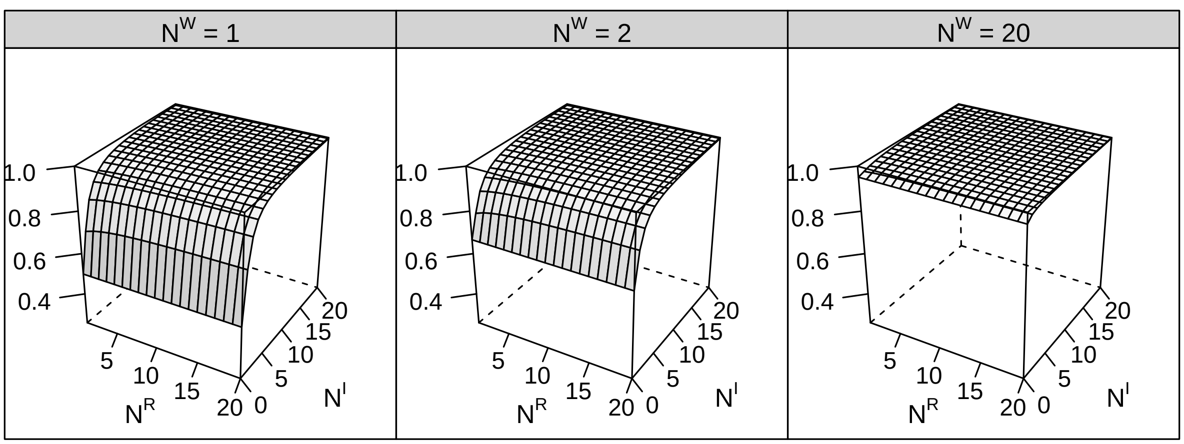
C.2 Numerical solutions to theoretical model

Figure C1: $\partial P^R/\partial \tau$



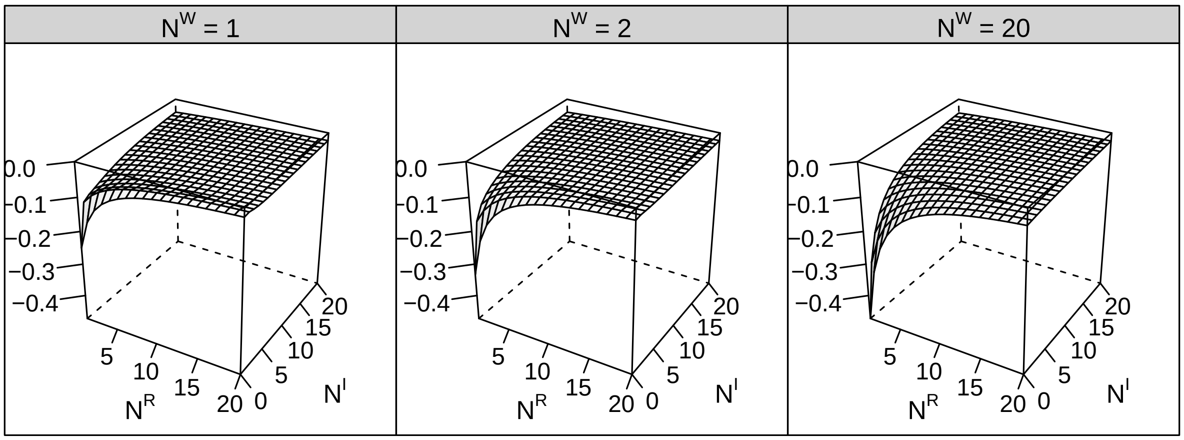
Notes: Showing the derivative of the retail price with respect to the tax.

Figure C2: $\partial P^W/\partial \tau$



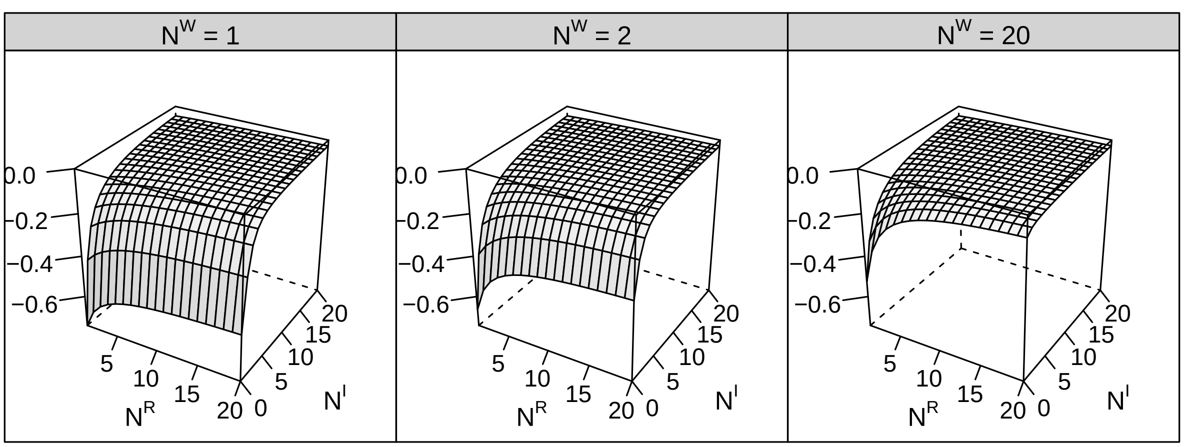
Notes: Showing the derivative of the wholesale price with respect to the tax.

Figure C3: $\partial M^R/\partial\tau$



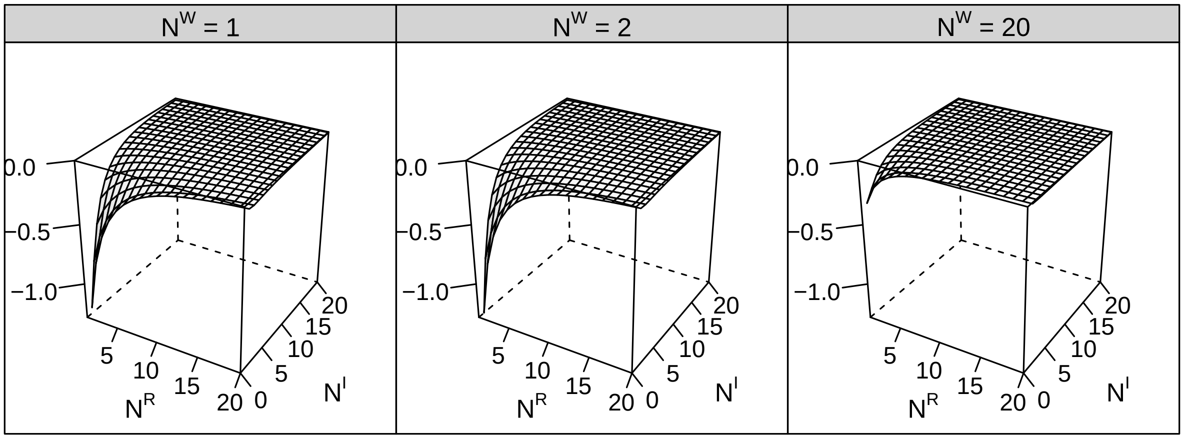
Notes: Showing the derivative of a retail-only firm's margin with respect to the tax.

Figure C4: $\partial M_I^R/\partial\tau$



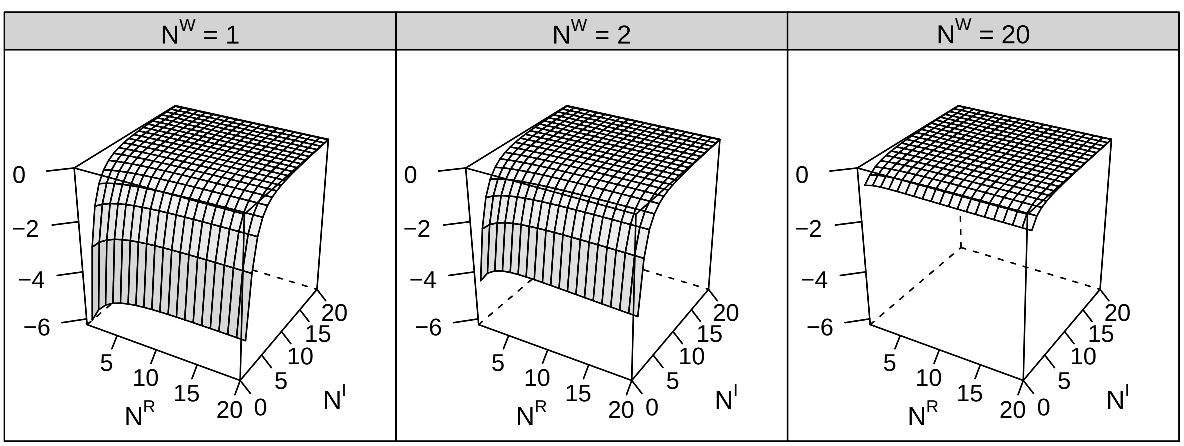
Notes: Showing the derivative of an integrated firm's margin in the retail market with respect to the tax.

Figure C5: $\Delta^R(P^W)$



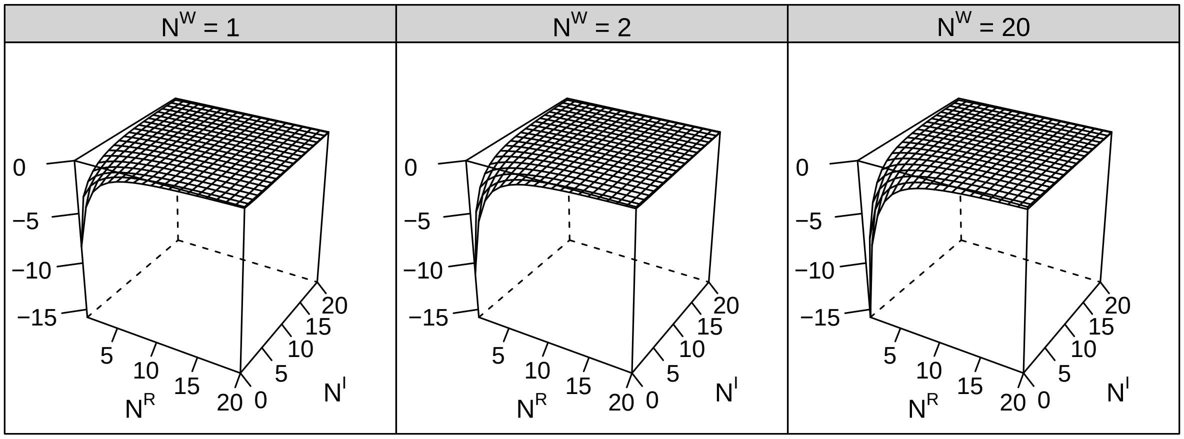
Notes: Showing the change in the wholesale price when a retail-only firm enters.

Figure C6: $\Delta_I^R(P^W)$



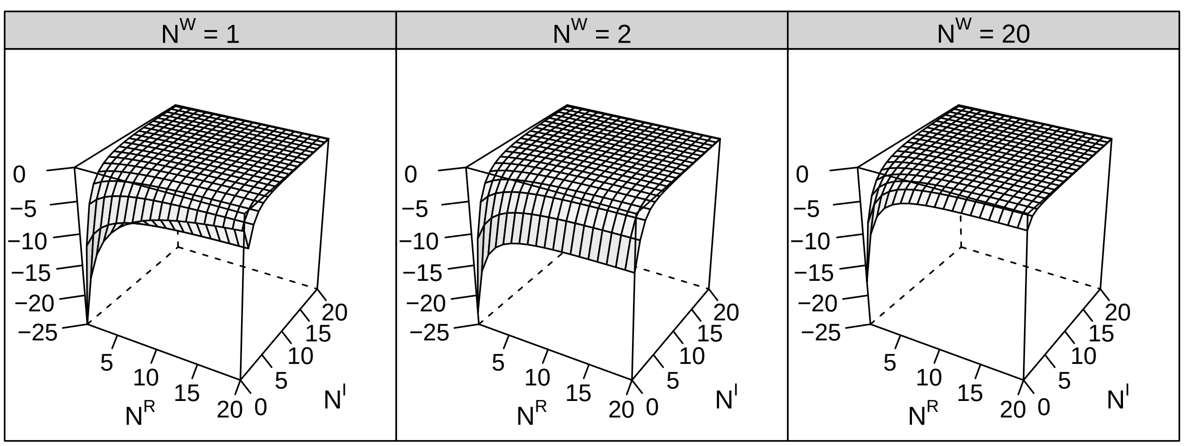
Notes: Showing the change in the wholesale price when a wholesale-only firm opens a retail site (becomes integrated).

Figure C7: $\Delta^R(P^R)$



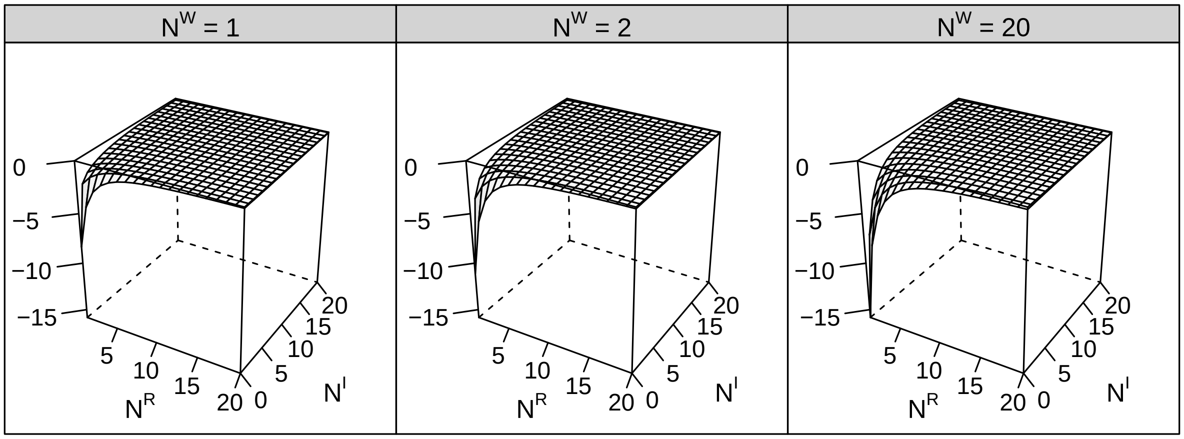
Notes: Showing the change in the retail price when a retail-only firm enters.

Figure C8: $\Delta_I^R(P^R)$



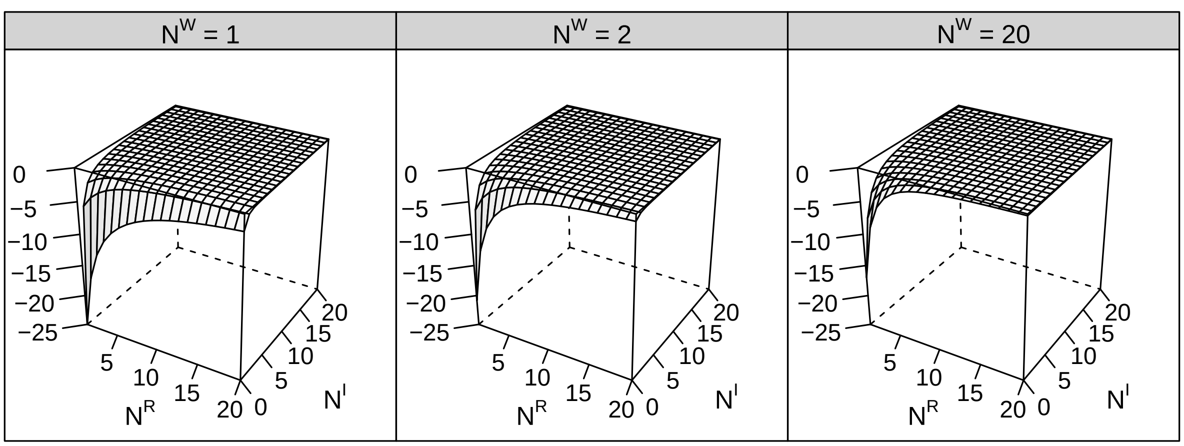
Notes: Showing the change in the retail price when a wholesale-only firm opens a retail site (becomes integrated).

Figure C9: $\Delta^R(M^R)$



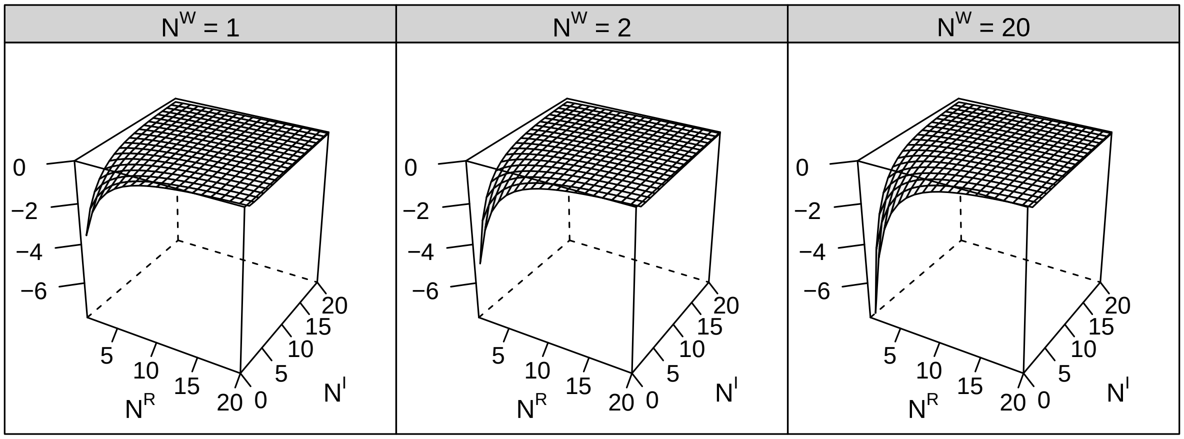
Notes: Showing the change in a retail-only firm's margin when another retail-only firm enters.

Figure C10: $\Delta_I^R(M^R)$



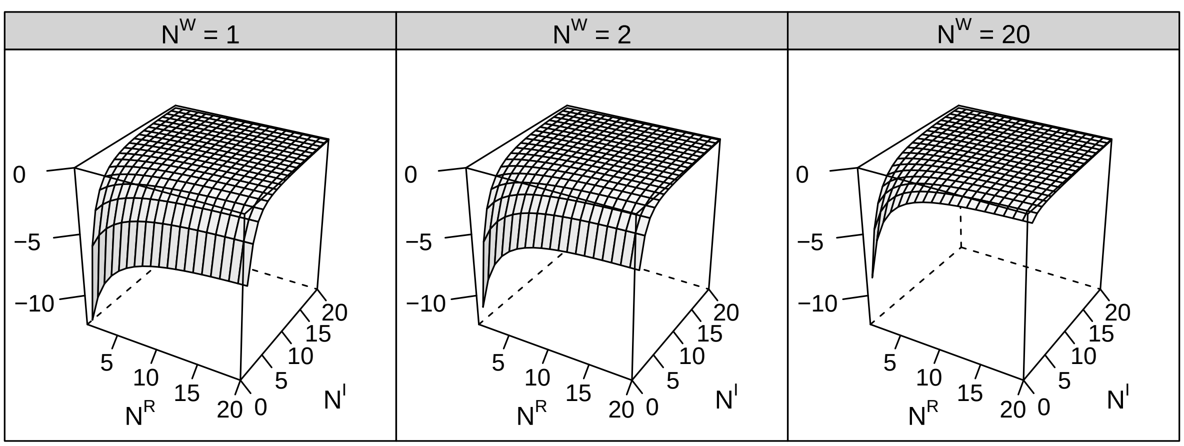
Notes: Showing the change in a retail-only firm's margin when a wholesale-only firm opens a retail site (becomes integrated).

Figure C11: $\Delta^R(M_I^R)$



Notes: Showing the change in an integrated firm's retail margin when a retail-only firm enters.

Figure C12: $\Delta_I^R(M_I^R)$



Notes: Showing the change in an integrated firm's retail margin when a wholesale-only firm opens a retail site (becomes integrated).

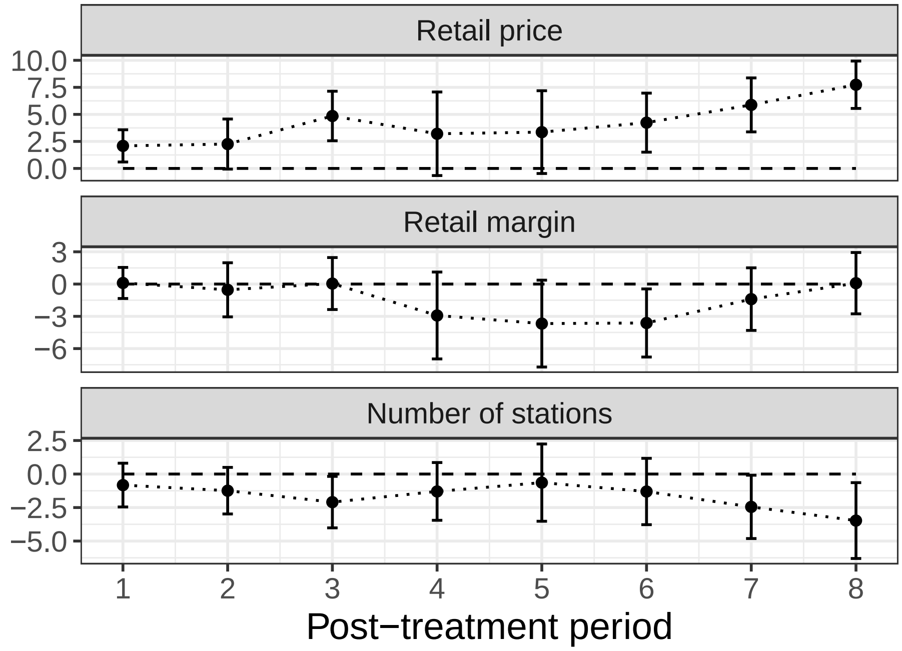
D Lasso selected controls

Table D1: NAICS control industires

Number	Name
442210	Floor covering stores
442291	Window treatment stores
442292	Print and picture frame stores
442298	All other home furnishings stores
444110	Home centres
444190	Other building material dealers
445110	Supermarkets and other grocery (except convenience) stores
445120	Convenience stores
445210	Meat markets
445220	Fish and seafood markets
445230	Fruit and vegetable markets
445291	Baked goods stores
445292	Confectionery and nut stores
445299	All other specialty food stores
445310	Beer, wine and liquor stores
446199	All other health and personal care stores
448130	Children's and infants' clothing stores
448191	Fur stores
448210	Shoe stores
451120	Hobby, toy and game stores
451140	Musical instrument and supplies stores
452110	Department stores
452999	All other miscellaneous general merchandise stores
453110	Florists
453220	Gift, novelty and souvenir stores
453310	Used merchandise stores
453910	Pet and pet supplies stores
453920	Art dealers
453992	Beer and wine-making supplies stores
454210	Vending machine operators
454390	Other direct selling establishments

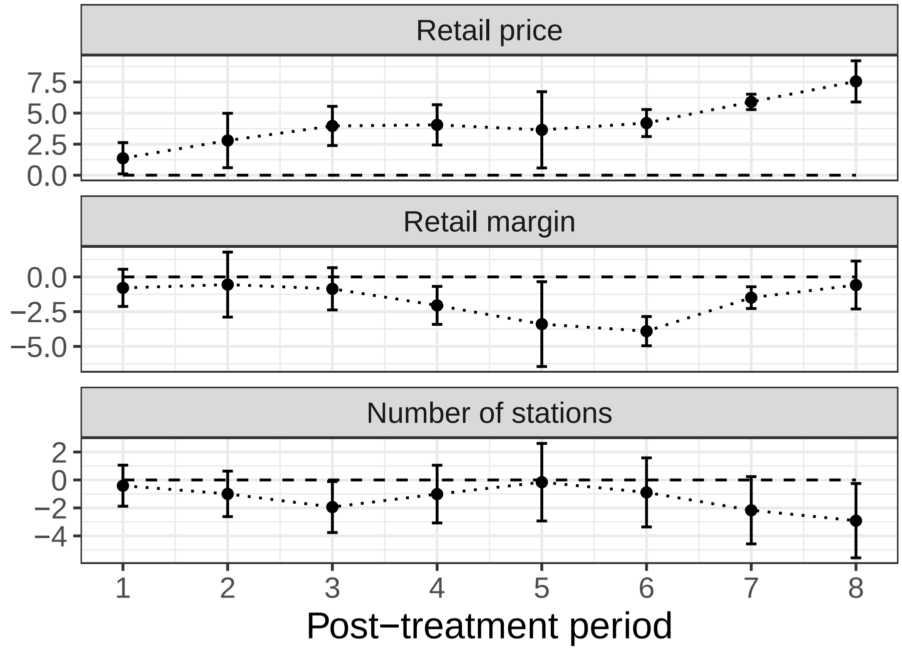
E Robustness

Figure E1: DiD estimates of δ - Without Alberta



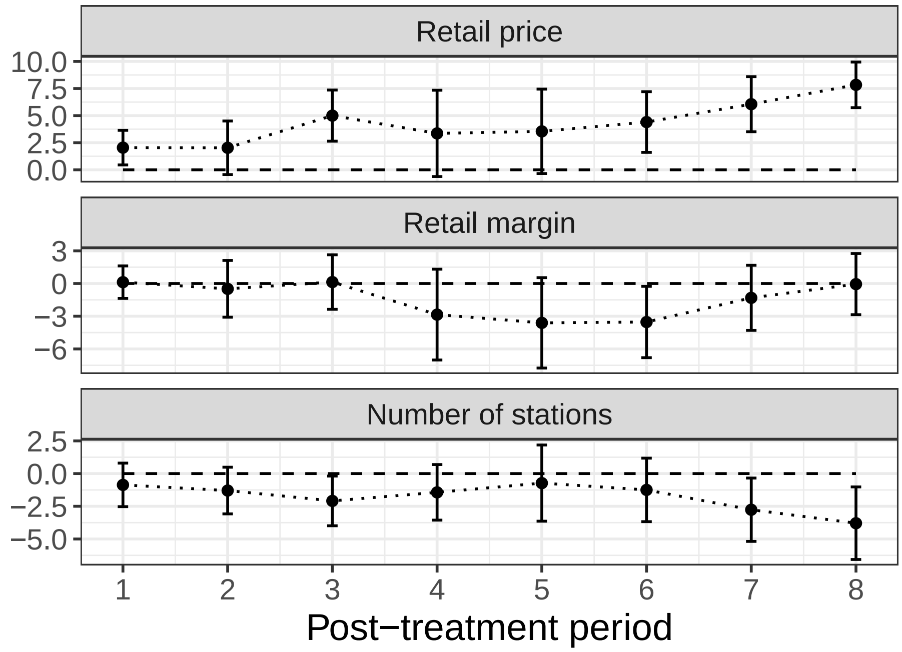
Notes: The error bounds are 95% confidence intervals with standard errors clustered by geographic unit.

Figure E2: DiD estimates of δ - Without Vancouver and Victoria



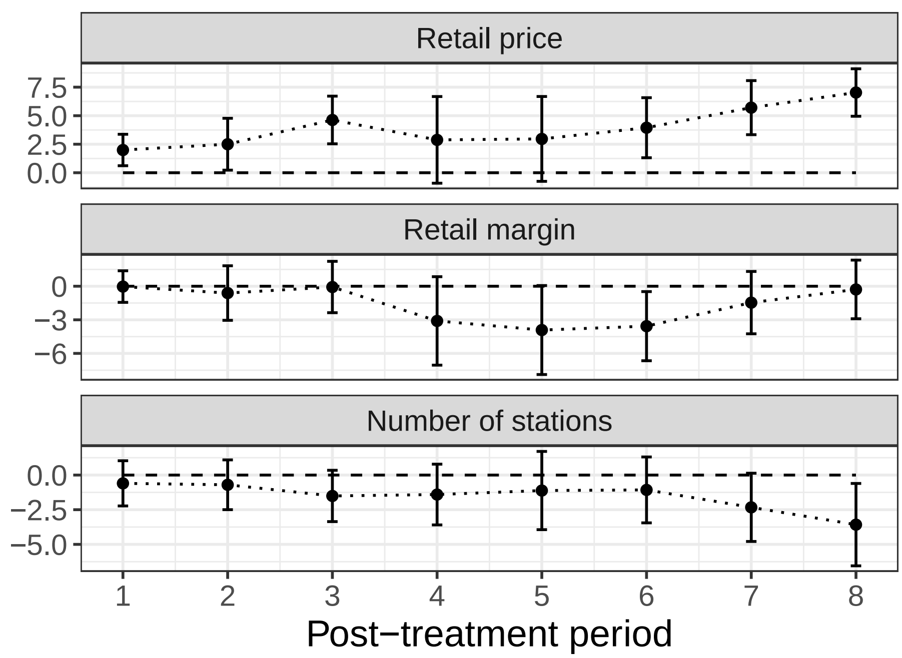
Notes: The error bounds are 95% confidence intervals with standard errors clustered by geographic unit.

Figure E3: DiD estimates of δ - Reduced pre-treatment period



Notes: The error bounds are 95% confidence intervals with standard errors clustered by geographic unit.

Figure E4: DiD estimates of δ - All provinces in control group



Notes: The error bounds are 95% confidence intervals with standard errors clustered by geographic unit.